Final report on storage of vegetable products in expanded polystyrene packages

Report for the EUMEPS POWER PARTS

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Foreword

This final report includes the results of the study regarding the i) the storage of broccoli floret heads in expanded polystyrene packages or corrugated carton boxes at 5 or 10^oC combined or not with trimmed ice ii) the storage of tomato fruits in expanded polystyrene packages or corrugated carton boxes at 10 or 20^oC and iii) the storage of spinach leaves in expanded polystyrene packages or corrugated carton boxes at 5 or 10^oC and was based on the study that is conducted in the Laboratory of Vegetables Crops, Department of Horticulture, Aristotle University of Thessaloniki, on behalf of EUMEPS POWER PARTS, in the framework of a funded project.

Report on Broccoli Storage in EPS package

Abstract

Three hundred freshly harvested broccoli floret heads were transferred to the Laboratory of Vegetable Crops at the Farm of Aristotle University of Thessaloniki and were placed in a 0^{o}C cold room for one day. The next day, the color of all the broccoli florets was measured with a colorimeter, and then the heads were sorted and divided before being placed into different packages and particularly in expanded polystyrene (EPS) or corrugated carton fruit packing boxes, both with and without trimmed ice. Each type of package was replicated four times. The ice was added above the broccoli floret heads and a plastic bag was used to avoid water leakage. Data loggers were also placed inside the 4 different packages to record the temperature and the relative humidity conditions inside the package. Then half the packages of each material were placed in 5^{o}C, which is recommended for broccoli storage and the rest in 15^{o}C, which is the most common temperature that exists during the disposal of the product in non-refrigerated shelves in the market stores. The trimmed ice inside the packages at 15^{o}C melted rapidly within one day and the resulting water was removed the following day, while the ice inside the packages at 5^{o}C lasted longer, but it was eventually removed after four days, as well. Three floret heads from each package were sampled every week for weigh and color measurements, as well as nutritional components determination, namely dry matter, soluble solids, pH, total antioxidant capacity, soluble phenols and ascorbic acid. At both storage temperatures, slightly higher temperature levels were recorded inside the EPS packages than in the corrugated carton boxes, while the relative humidity was maintained high in the EPS packages at both temperatures, due to the insulation that is offered by such a closed package system, in contrast to the open corrugated carton packages where a severe variation in the relative humidity was daily recorded. The storage of broccoli floret heads at 15^{o}C even for 1 week resulted in severe yellowing appearance of the buds on the florets, rendering the heads and unmarketable and were therefore not sampled for the next two weeks. Yellow discoloration developed also on florets stored at 5^{o}C on the 3rd week of storage, especially on broccoli heads placed inside the EPS packages, due to the accumulation of ethylene, which is a gas senescence stimulator compound. The addition of ice is not recommended, because it melted rapidly, and the remaining water

boosts the proliferation and infestation of fungal and bacterial diseases. Apart from the advantages of the use of EPS in the storage of broccoli florets at 5°C, in terms of maintaining the weight of the heads while slightly affecting the dark green color of the buds, also the nutritional composition of the tissue was best maintained, and particularly the dry matter, the soluble solids, the soluble phenols, the ascorbic acid and the antioxidant capacity. That way, the consumers will enjoy an attractive, tender and nutritious product without being concerned regarding the safety risks, that may be induced during the melting of the ice into water that can easily be converted into a substrate for microbial infestations.

Materials and methods

On June 2018, 300 broccoli floret heads, harvested the day before, were transferred to the Laboratory of Vegetable Crops at the Farm of Aristotle University of Thessaloniki by the commercial company “SAPOUNTZOGLOU MARKOS SA” in a refrigerated truck. The floret heads were weighed and 12 floret heads (4 replications of 3 floret heads each) were frozen immediately for analysis, representing Day 0 samples. The remaining floret heads along with all the packages were placed in a cold room at 0°C for one day, so that both the floret heads and the inner side of each package would be at the same low temperature. The next day, the color of the broccoli floret heads was measured with a colorimeter, and then the floret heads were placed into the packages with 9 floret heads per package. The packages used were i) EPS and ii) corrugated carton fruit packing box both without trimmed ice, as well as iii) EPS and iv) corrugated carton fruit packing box both with trimmed ice. Each type of package was replicated four times. The ice was added above the broccoli floret heads and a plastic bag was used to avoid water leakage. Data loggers were also placed inside the 4 different packages to record the temperature and the relative humidity conditions inside the package. Then the packages were placed in two different storage temperatures, 5°C and 15°C, and this was marked as Day 0.

The ice inside the packages that were stored at 15°C melted immediately and the water was removed the following day. The ice inside the packages that were stored at 5°C lasted longer, but it was eventually removed after four days, as well.

On Day 7, three floret heads from each package were removed. The weight and the color were measured, and they were frozen for nutritional composition analysis. The storage of broccoli heads at 15°C was discontinued, because all heads had already turned yellow and therefore rendered unmarketable. On Day 14 and Day 21, three floret heads of each package were removed only from the 5^{o}C storage. The weight and color were determined, and they were frozen for further analysis as previously described.

The main nutritional components on each floret were determined, namely dry matter, soluble solids, pH, total antioxidant capacity, soluble phenols and ascorbic acid. All the data was statistically processed, and the results are presented below.

Results

Temperature and relative humidity

The temperature in all the packages quickly rose from 0^{o}C to 5 or 15^{o}C, respectively, depending on the storage temperature (Fig. 1&2). Specifically, inside the packages stored at 5^{o}C, the temperature in the EPS and the corrugated carton package without the addition of trimmed ice reached the ambient temperature in less than half day. In the packages that trimmed ice was added above the florets, the temperature in the corrugated carton package reached the external temperature within 3 days, while the EPS package retained the temperature lower than the ambient one for additionally one more day, but the ice had already melted until the end of fourth day. After the ice was discarded, the temperature in both packages previously supplemented with ice did not differ than the temperature in the packages where no ice was initially added. Inside all the packages with the broccoli florets stored at 15^{o}C, the temperature reached the ambient room temperature in a few hours when no ice was previously added, or the next day in the packages that trimmed ice was included.

At both storage temperatures, higher temperature levels were recorded in EPS packages than in the corrugated carton box. This is occurring because the EPS package is a closed package system and the heat that is produced during plant respiration is trapped inside the package. The maximum temperatures recorded in the packages that were stored at 5 and 15^{o}C, respectively, were: 10.3 and 16.2^{o}C in EPS package with ice, 9.1 and 16.7^{o}C in EPS package without ice, 10.6 and 14.7^{o}C in corrugated carton package with ice, and 12.4 and 14.7^{o}C in corrugated carton package without ice. The average storage temperatures in the packages that were stored at 5 and 15^{o}C, respectively, were: 5.0 and 14.1^{o}C in EPS package with ice, 5.8 and 15.5^{o}C in EPS package without ice, 4.6 and 13^{o}C in corrugated carton package with ice, and 5.1 and 13.9^{o}C in corrugated carton package without ice.

Significant daily temperature fluctuation was observed in the cold rooms, which was more pronounced at the storage temperature of 5^{o}C, due to the continuous operation of the cooling fans. Moreover, the addition of trimmed ice had no practical value in preserving a low temperature, as long as it rapidly melted, which is considered as a drawback in fresh produce postharvest preservation due to fungal disease attack potential hazard.

The relative humidity was stable in the EPS packages that were stored at both temperatures (Fig. 3&4), due to the insulation that is offered by such a closed package system, while in the corrugated carton package, severe variation in the relative humidity was observed. Higher relative humidity variation was observed at the 5^{o}C storage temperature, due to the continuous circulation of the air by the cooling, and in turn this last one contributed to the dehydration of the broccolis placed in the corrugated carton package, resulting in a significant weight loss.

The minimum relative humidity levels recorded in the packages that were stored at 5 and 15^{o}C respectively were: 94.8 and 96.1% in EPS package with ice, 91.4 and 85.1% in EPS package without ice, 81.2 and 90.9% in corrugated carton package with ice, and 74.4 and 77.8% in corrugated carton package without ice. The average storage temperatures in the packages that were stored at 5 and 15^{o}C respectively were: 100.0 and 99.9% in EPS package with ice, 100 and 99.8% in EPS package without ice, 96.5 and 99.0% in corrugated carton package with ice, and 89.8 and 98.6% in corrugated carton package without ice.

Color

The color of the broccoli floret heads was measured on three spots on the floret head of each broccoli, with a Minolta CR-200 colorimeter. Five different parameters were determined, lightness (L*), a*, b*, chroma (C*) and hue angle (h^{o}).

Lightness (L*) describes the brightness of a tissue and takes values between 0 that corresponds to black color and 100 that corresponds to white. In the first week (day 7) of storage there were no changes in L* in the floret heads stored at 5 ^{o}C, but there were significant changes in the floret heads stored at 15 ^{o}C (Fig. 5&6). L* increased significantly in all packages used, compared to day 0. The highest increase was observed in floret heads stored at 15^{o}C in EPS packages with ice (52.5). L* increased on the second week (day 14) in broccoli heads at 5 ^{o}C in EPS with or without ice, as well as in corrugated carton package without ice. On the third week (day 21), L* further increased in broccolis in the EPS packages with or without ice and in corrugated carton package with ice. The highest increase was observed in floret heads held at 5^{o}C in EPS packaging without the addition of trimmed ice on the third week. Increase in lightness values indicates that the color of the heads had started to become less bright than at the beginning of the storage, namely less shiny.

Color parameters a* and b* represents the coordinates on a color wheel, corresponding to the red (+a*), green (-a*), yellow color (+b*) and blue color (-b*). In our study, the parameter a* had only negative values for all broccoli floret heads in all packages during the whole storage period. However, on the first week of storage, a* values increased in floret heads stored at 15^{o}C in EPS with ice and in corrugated carton package with or without ice (data not shown). On the contrary, in the broccoli floret heads stored at 5^{o}C, the a* parameter remained stable for two weeks and it decreased only in the broccoli floret heads held in the EPS package with ice for three weeks. Concerning parameter b*, no significant change was observed in broccoli floret heads stored at 5^{o}C on the first week of storage, but there was an increase in the heads stored at 15^{o}C in all packages, indicating the yellow color that developed on the florets (data not shown). On the second week, b* values increased significantly only in broccoli heads placed in EPS package without ice, and on the third week, b* values increased significantly only in floret heads in EPS package with or without ice and in corrugated carton package with ice. However, this increase was much lower than the increase that was observed in floret heads stored at 15 ^{o}C.

Chroma (C*) represents the vividness (high values) or dullness (low values) of a color. On the first week, significant increase in C* was observed only in the broccoli floret heads that were stored at 15^{o}C (Fig. 6). On the second week, C* increased significantly only in floret heads stored at 5^{o}C in EPS package without ice, and on the third week, C* increased significantly in floret heads stored at 5^{o}C in EPS package with or without ice and in corrugated carton package with ice, as well (Fig. 5).

Hue angle describes the hue of the color and each degree corresponds to a specific color (0^{o} for red, 90^{o} for yellow, 180^{o} for green, 270^{o} for blue). On the first week, significant changes in hue angle were observed only in broccoli stored at 15^{o}C (Fig. 6). Hue angle decreased from 129-130^{o} to 103-109^{o}, reaching the values close to the yellow color. On the second week, hue angle decreased only in floret heads stored at 5^{o}C in EPS packaging without ice and on the third week, it decreased in floret heads stored at 5^{o}C in EPS packaging with or without ice and in corrugated carton package with ice (Fig. 5). At the 5^oC storage temperature, the lowest hue angle value was observed in EPS package without ice on the third week (119^o).

According to the color changes, it is concluded that the greater changes were observed in the broccoli floret heads stored at 15^oC in all packages within the first week of storage and in the broccoli floret heads stored at 5^oC in EPS package with or without ice on the third week of storage. In all these cases, the floret heads had already turned into yellow. Color changes were also observed on the second week of storage at 5^oC in EPS package with or without ice. However, these changes were not significant ones, in order to make these broccoli floret heads turn yellow, which would render them unmarketable. The differences among the EPS and the corrugated carton packages are attributed to the fact that EPS is a closed packaging system, which means that the ethylene and the carbon dioxide produced by the broccoli floret heads is trapped inside the package; thus inducing the faster aging of the floret heads and their yellowing, because ethylene is considered a gas ripening stimulating agent and broccoli is sensitive to ethylene presence in the storage area.

Weight loss

The weight loss of the broccoli floret heads is brought about due to water loss, which occurs during the respiration and transpiration of a living plant tissue, such as a broccoli head. Both respiration and transpiration rates depend strongly on the relative humidity of the surrounding area of the floret heads. High relative humidity decreases the respiration rate.

On the first week of storage, significant differences in the weight loss were observed in broccoli floret head stored at 5^oC in EPS package without ice and in corrugated carton package with or without ice, and in floret heads stored at 15^oC in all packages, compared to day 0 (Fig. 7&8). Weight loss at 5^oC was significantly higher in floret heads stored in the corrugated carton package without ice (17%), compared to EPS package without ice (6%). Higher weight loss was similarly observed in broccoli heads held in corrugated carton package with ice (7%) and EPS package with ice (2%). In florets stored at 15^oC, weight loss was again greater in the corrugated carton packages either without ice (14%) or with ice (12%), compared to EPS package with ice (9%) and without ice (8%).

On the second week, further significant increase in the weight loss of floret heads stored at 5°C was only observed in corrugated carton packages with or without ice (16 and 29%), while it remained low in the EPS packages (4-6%).

Weight loss was continuously increasing during storage of broccoli heads in the corrugated carton package with and without ice even during the third week, reaching the extreme levels of 26-39%, while the weight loss in EPS packages with or without ice remained at the same low levels as the previous week (4-7%, respectively).

The significant weight loss of 17% that was observed within the first week of storage at 5°C in the corrugated carton package without ice, which is the conventional packaging system in broccoli distribution, implies a severe commercial loss in the market, apart from a significant quality deterioration of the tissue, due to the rubber texture obtained by the florets; thus rendering the heads unattractive to the consumers and in turn unmarketable. On the other hand, the addition of trimmed ice in the corrugated carton packages is not considered as a practical means in broccoli distribution and cannot be adapted by the market, due to the absence of any insulation cover that cause the rapid melting of the ice and the wetting of the carton resulting in the development of phytopathological diseases. According to the above, the conventional commercial packaging system is apparently incapable to maintain the freshness of broccoli floret heads even for a one-week storage period in a low temperature, due to excessive weight loss. The minimal weight loss observed in the EPS package is the result of the protected, insulated packaging system which, regardless the addition of ice, preserves a high relative humidity (100%), and reduces the transpiration rate and consequently the weight loss.

However, the color deterioration of the floret heads appearing on the third week of storage implies that regardless the slight weight loss, it is recommended that broccoli floret heads should not be stored for more than two weeks even in the EPS packages even at 5°C. For that reason, the nutritional quality components will be examined until the second week of storage (day 14) in the following section. Moreover, the rapid quality deterioration, in terms of both color and weight loss, observed at 15°C suggests that broccoli floret heads cannot be stored at such temperature, which is strangely encountered every day during broccoli heads disposal in the market and is indeed the minimum temperature inside a supermarket store.

Nutritional quality

Dry matter increases in vegetables when there is water loss due to transpiration; thus, rendering the tissue less tender during consumption. During the first 2 weeks of storage at 5^{o}C, broccoli floret heads stored in EPS package with or without ice slightly decreased from 12% to 11% (Fig. 9). The decrease in dry matter was probably due to moisture re-absorption from the humid atmosphere inside the package. On the other hand, dry matter increased significantly in floret heads stored at 5^{o}C in corrugated carton package with or without ice reaching 13 and 15%, respectively. Dry matter of floret heads stored at 15^{o}C EPS packages was also increased (Fig. 10), probably due to water absorption, similar to the 5^{o}C and remained unchanged in corrugated carton packages with or without ice.

Total soluble solids content includes all sugars and organic acids that are responsible for the flavor in vegetables. During the first two weeks of storage at 5^{o}C, significant increases in total soluble solids were observed in broccoli floret heads held in corrugated carton package both with and without ice and decreased slightly in heads placed in EPS + ice without being affected in EPS without ice (Fig. 9). The increase in soluble solids is due to water loss, also reducing the tenderness of the tissue similarly as above, while the decrease is occurring because some of the sugars were consumed during the respiration process, as long as the weight of the heads was protected by the high relative humidity in the package.

During the first two weeks of storage, pH increased significantly in floret heads stored at 5^{o}C in EPS package with and without ice and remained at the initials levels in corrugated carton packaged broccoli heads both with and without ice (Fig. 11). Increases of pH were also found in florets stored at 15^{o}C in EPS package with or without ice and in corrugated carton package with ice (Fig. 12). In all cases, though, pH increased less than 0.2 units (from 5.8 to 6.0), which cannot be considered as a significant nutritional change and neither can be perceived by human during consumption.

Phenols and ascorbic acid are two of the main antioxidants in vegetables and, along with other components, they comprise the total antioxidant capacity. During the first two weeks of storage, phenol concentration increased significantly only in floret heads stored at 5^{o}C in corrugated carton package without ice (Fig. 11) and at 15^{o}C in EPS package without ice, compared to day 0 (Fig. 12).

In contrast, although there were no significant changes in ascorbic acid content in EPS with or without ice and carton boxes with ice at 5°C, a significant reduction was observed in florets stored in carton boxes without the addition of trimmed, being significantly lower especially with the heads stored in EPS packages (Fig. 13). No significant change was found in ascorbic acid of florets stored at 15°C, irrespectively of the packaging system (Fig. 14).

The antioxidant capacity of broccoli heads was maintained high during the 2-weeks storage period at 5°C, only when they were stored in EPS packages, irrespectively of the addition of ice, and was significantly higher than of the heads placed in carton boxes, where the antioxidant capacity was substantially reduced (Fig. 13). In contrary, when the floret heads were stored at 15°C, the reduction of antioxidants was found in EPS packaged broccoli and not in corrugated carton ones (Fig. 14), apparently due to the severe weight loss in the latter ones which resulted in the condensation of organic compounds inside the cellular space.

Conclusions

According to the above results, it is concluded that the quality of the broccoli floret heads, in terms of green color preservation and minimal weight loss, may be maintained at acceptable levels for only 2-week period, only when they are stored at 5°C in EPS boxes. When the broccoli floret heads were stored at 15°C, a temperature that is commonly occurring in the supermarket stores, the floret heads could not be stored even for 1 week, as they already turned yellow and unmarketable within 7 days. The same problem was observed even after 21 days in florets held at 5°C, either due to severe weight loss in the carton boxes, because of the absence of a cover protection or due to yellowing in the EPS packages, due to the trapping of ethylene gas inside the package atmosphere. Apart from the advantages of the use of EPS in the storage of broccoli florets at 5°C, in maintaining the weight of the heads while slightly affecting the dark green color of the buds, also the nutritional composition inside the tissue was best maintained, and particularly in terms of dry matter, soluble solids, phenolics, ascorbic acid and antioxidants especially when comparing the EPS packaging to the conventional corrugated carton boxes, without the use of ice. That way, the consumers will enjoy an attractive, tender and nutritious product without being concerned regarding the safety risks, that may be induced during the melting of the ice into water that can easily be converted into a substrate for microbial infestations.

Photo 1. Arrival of the broccoli floret heads to the Lab of Vegetable Crops.

Photo 2. Broccoli floret heads in expanded polystyrene packages with and without the addition of trimmed ice.

Photo 3. Trimmed ice placed above the broccoli floret heads in open corrugated carton packages (left) and melted ice inside the packages (on the right).

Photo 4. Yellowing discoloration on broccoli floret heads stored at 15°C for 1 week.

Photo 5. Postharvest diseases developed on broccoli floret heads, as a result of the melted ice inside the packages.

Photo 6. Broccoli floret heads stored for 2 weeks at 5ºC inside EPS without ice (above) and corrugated carton box without ice (below).

Photo 7. Broccoli floret heads stored for 3 weeks at 5^{o}C inside EPS with ice (above) and corrugated carton box with ice (below).

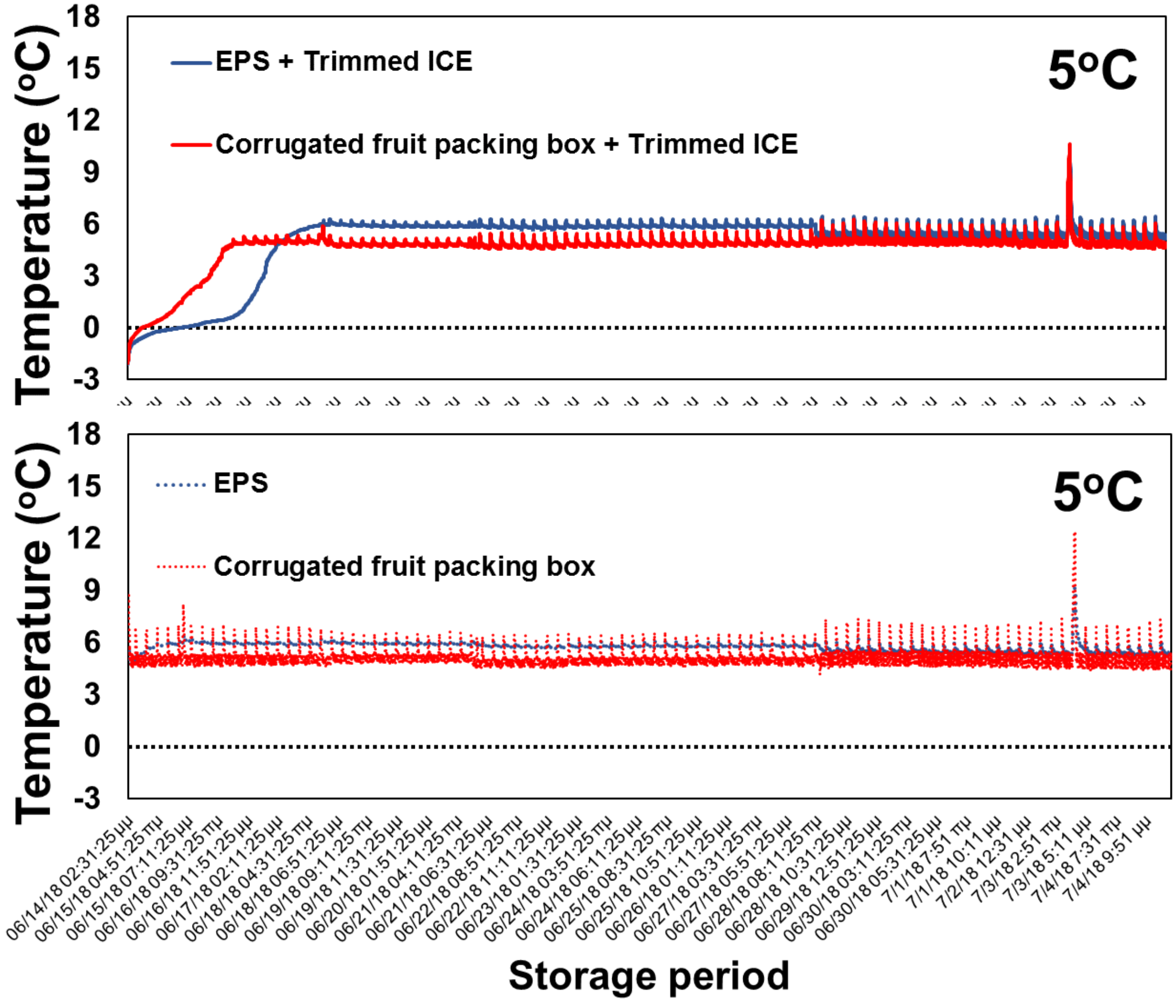


Figure 1. Temperature inside the EPS and the corrugated carton boxes at 5°C with (upper) and without trimmed ice (lower).

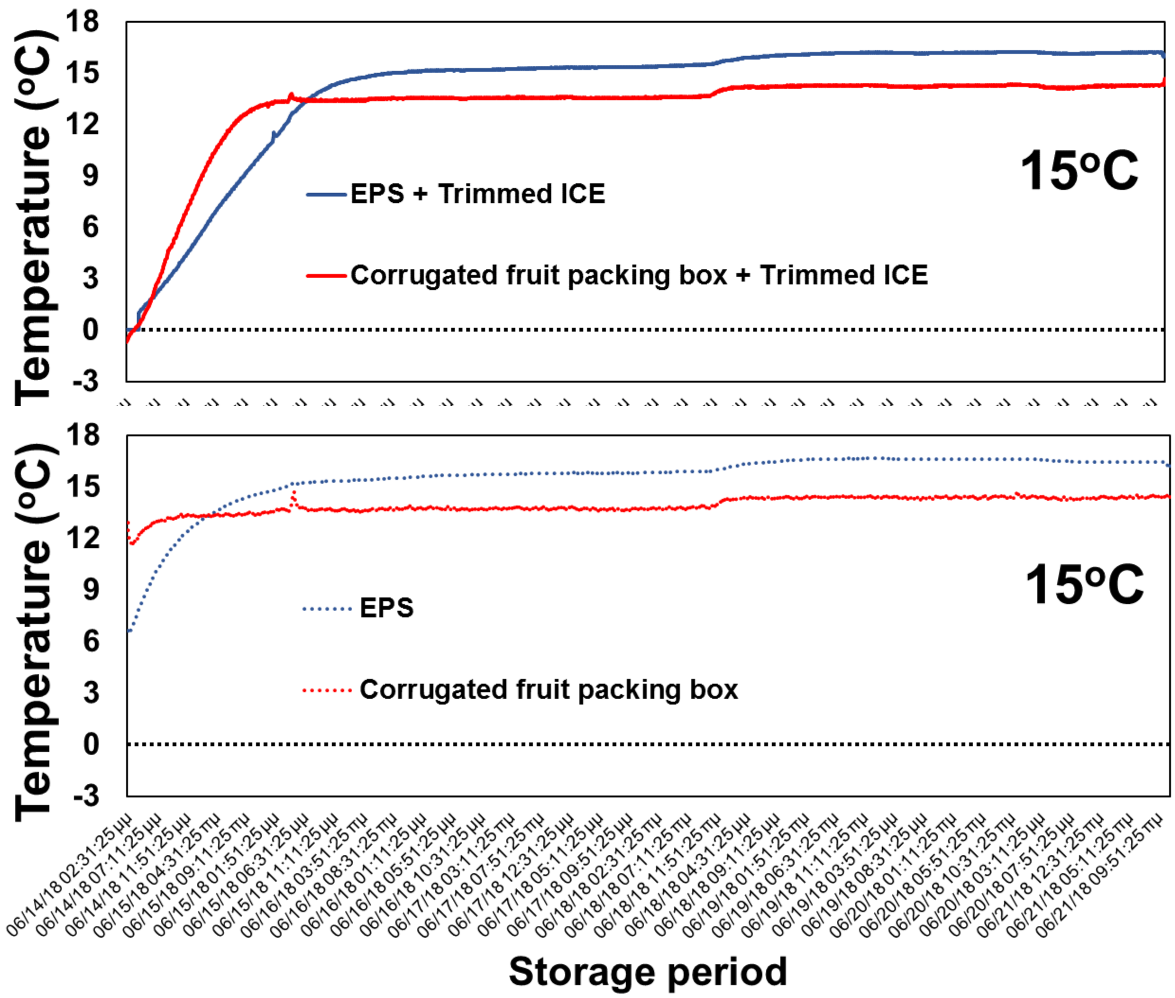


Figure 2. Temperature inside the EPS and the corrugated carton boxes at 15°C with (upper) and without trimmed ice (lower).

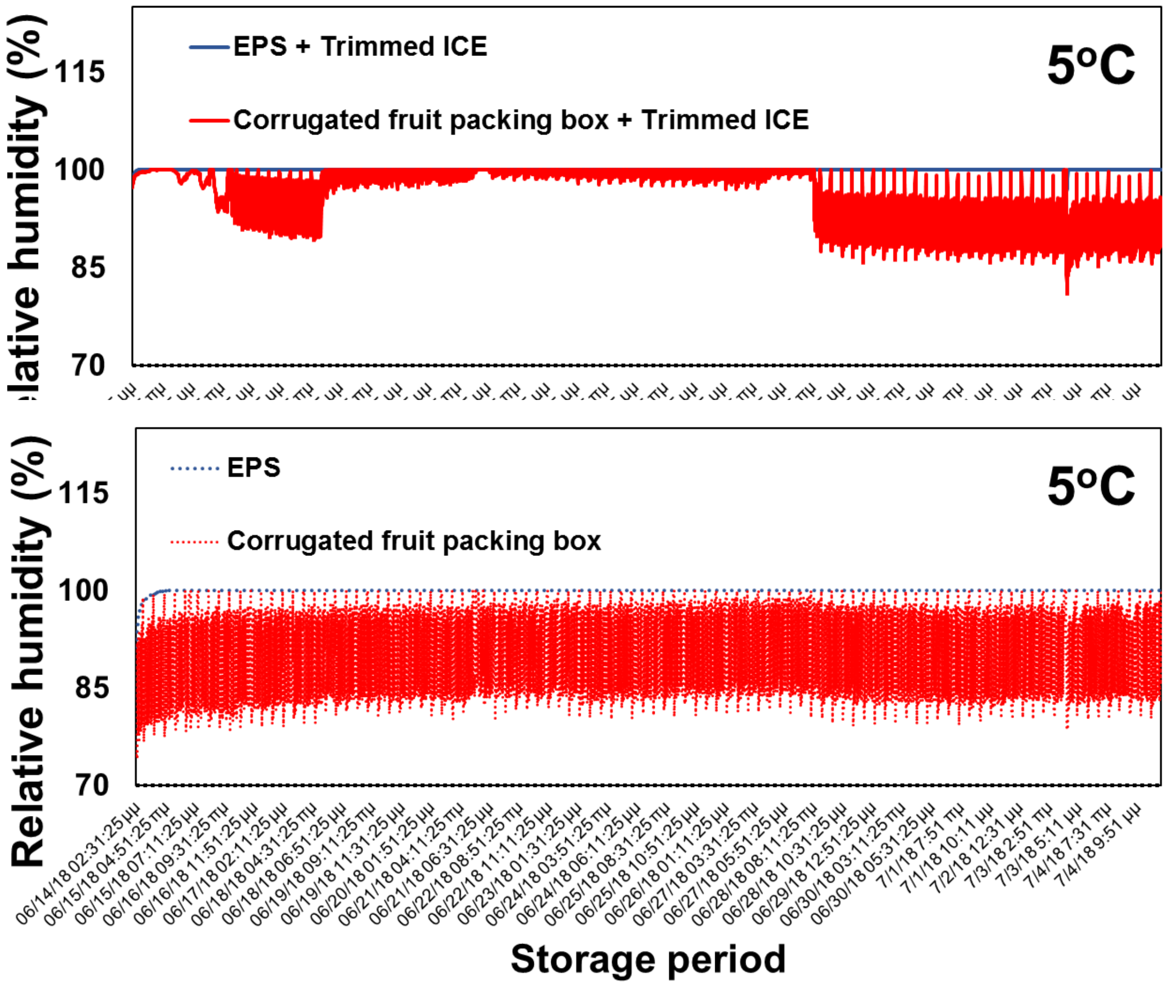


Figure 3. Relative humidity inside the EPS and the corrugated carton boxes at 5^{o}C with (upper) and without trimmed ice (lower).

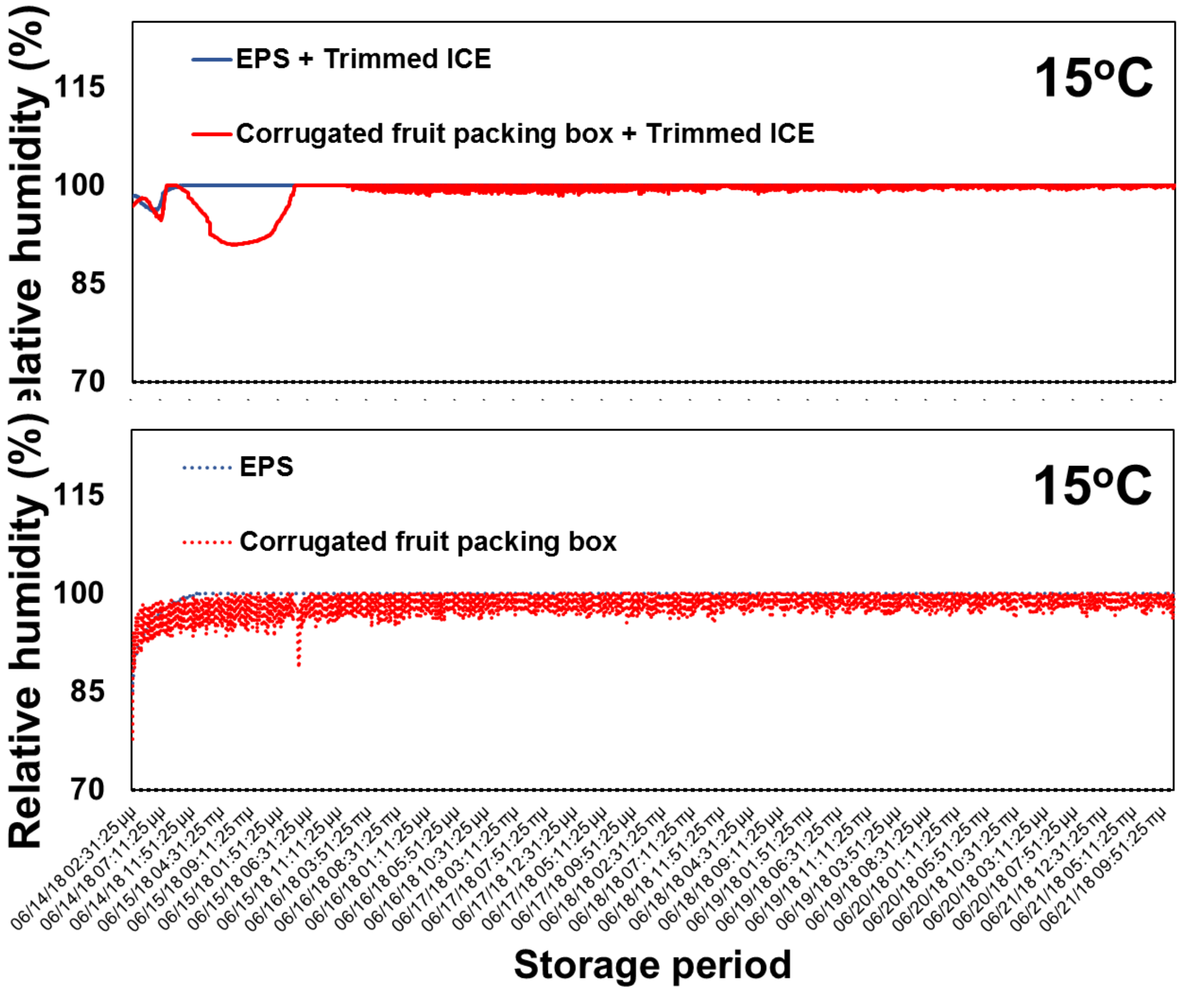


Figure 4. Relative humidity inside the EPS and the corrugated carton boxes at 15^{o}C with (upper) and without trimmed ice (lower).

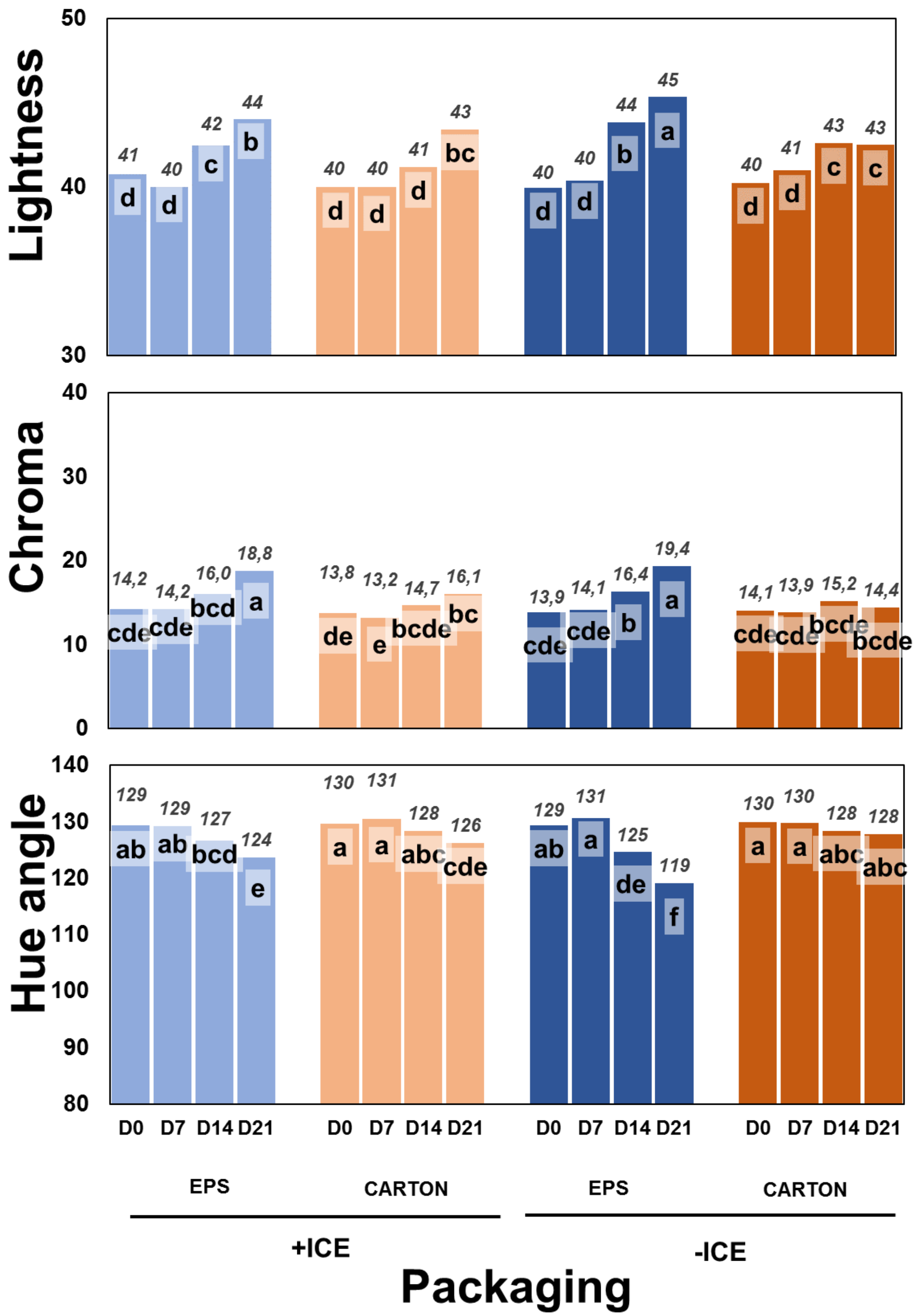


Figure 5. Color parameters (lightness, chroma and hue angle) of broccoli florets stored at 5ºC for 0, 7, 14 and 21 days in EPS or carton boxes with or without ice addition. Different letters in the columns imply significant statistical differences among the means.

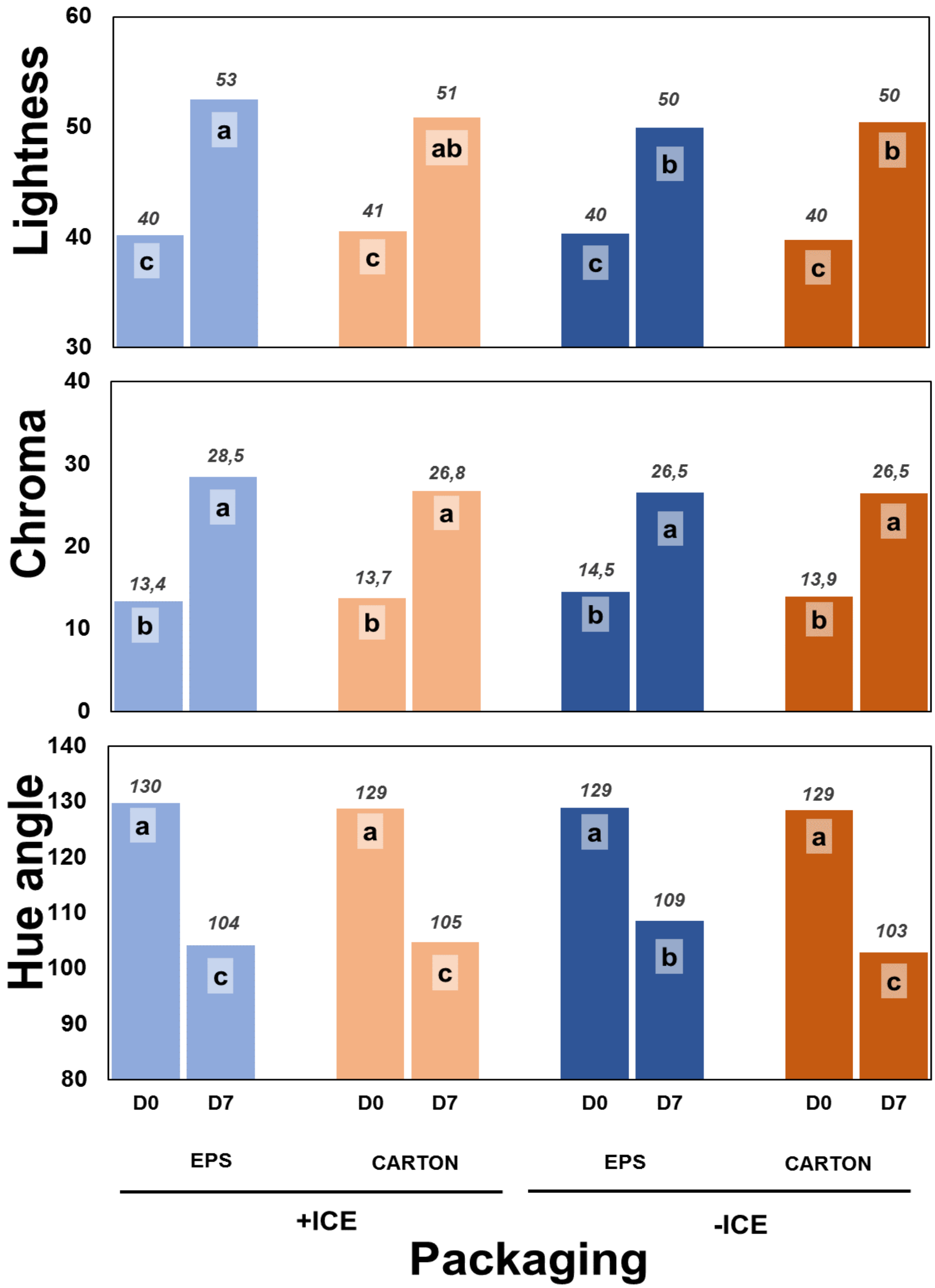


Figure 6. Color parameters (lightness, chroma and hue angle) of broccoli florets stored at 15°C for 0 and 7 days in EPS or carton boxes with or without ice addition. Different letters in the columns imply significant statistical differences among the means.

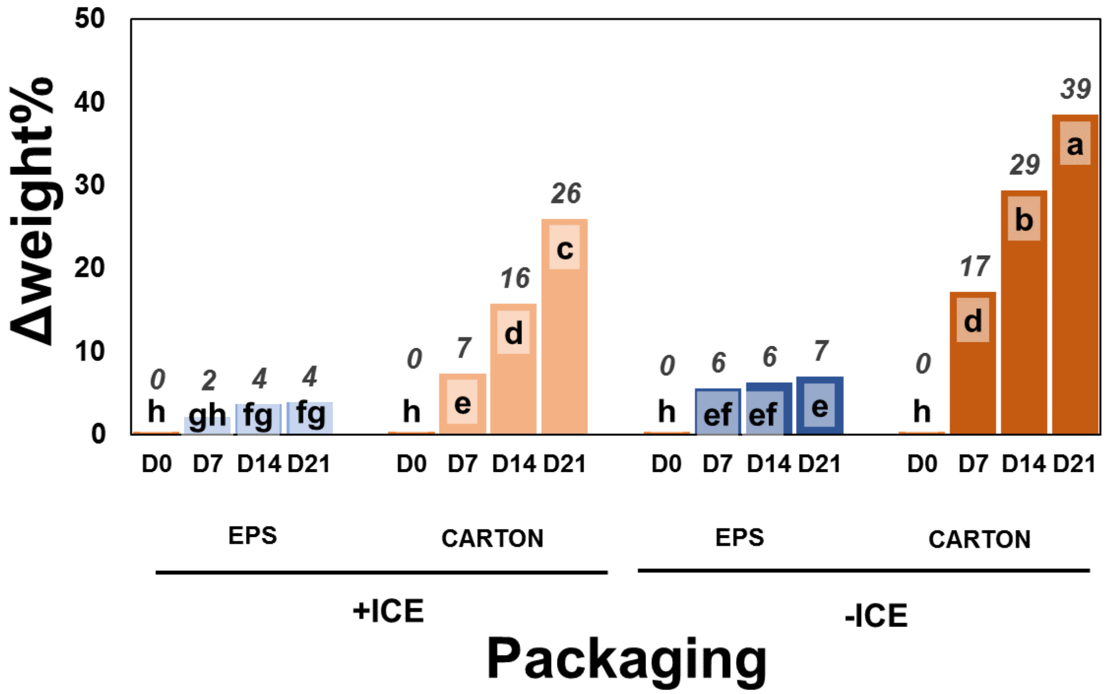


Figure 7. Fresh weight loss of broccoli florets stored at 5°C for 0, 7, 14 and 21 days in EPS or carton boxes with or without ice addition. Different letters in the columns imply significant statistical differences among the means.

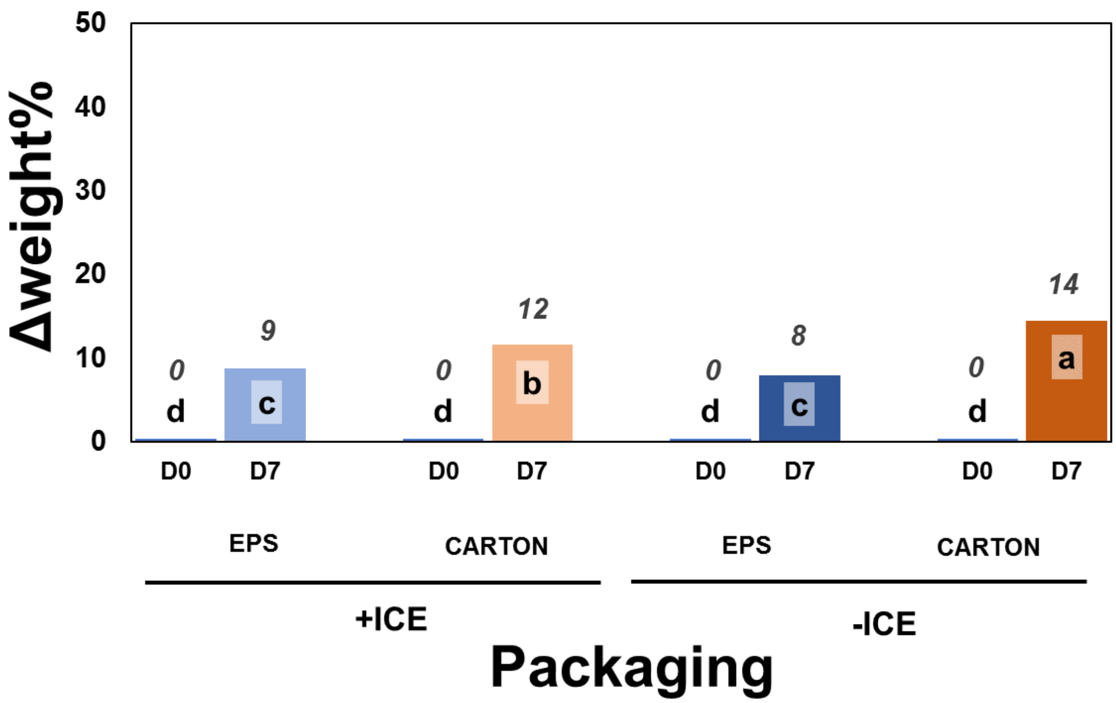


Figure 8. Fresh weight loss of broccoli florets stored at 15°C for 0 and 7 days in EPS or carton boxes with or without ice addition. Different letters in the columns imply significant statistical differences among the means.

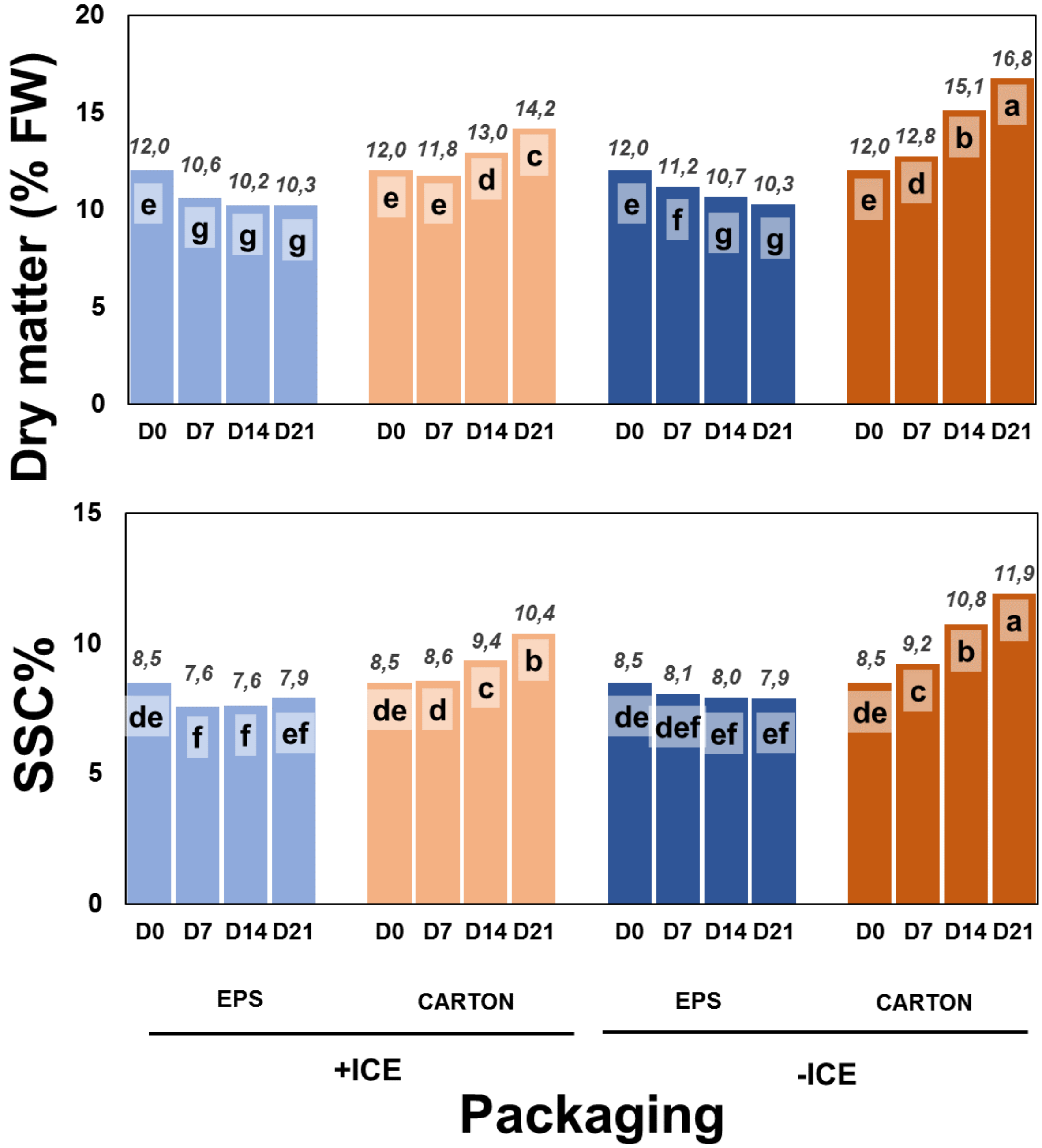


Figure 9. Dry matter and soluble solids content of broccoli florets stored at 5ºC for 0, 7, 14 and 21 days in EPS or carton boxes with or without ice addition. Different letters in the columns imply significant statistical differences among the means.

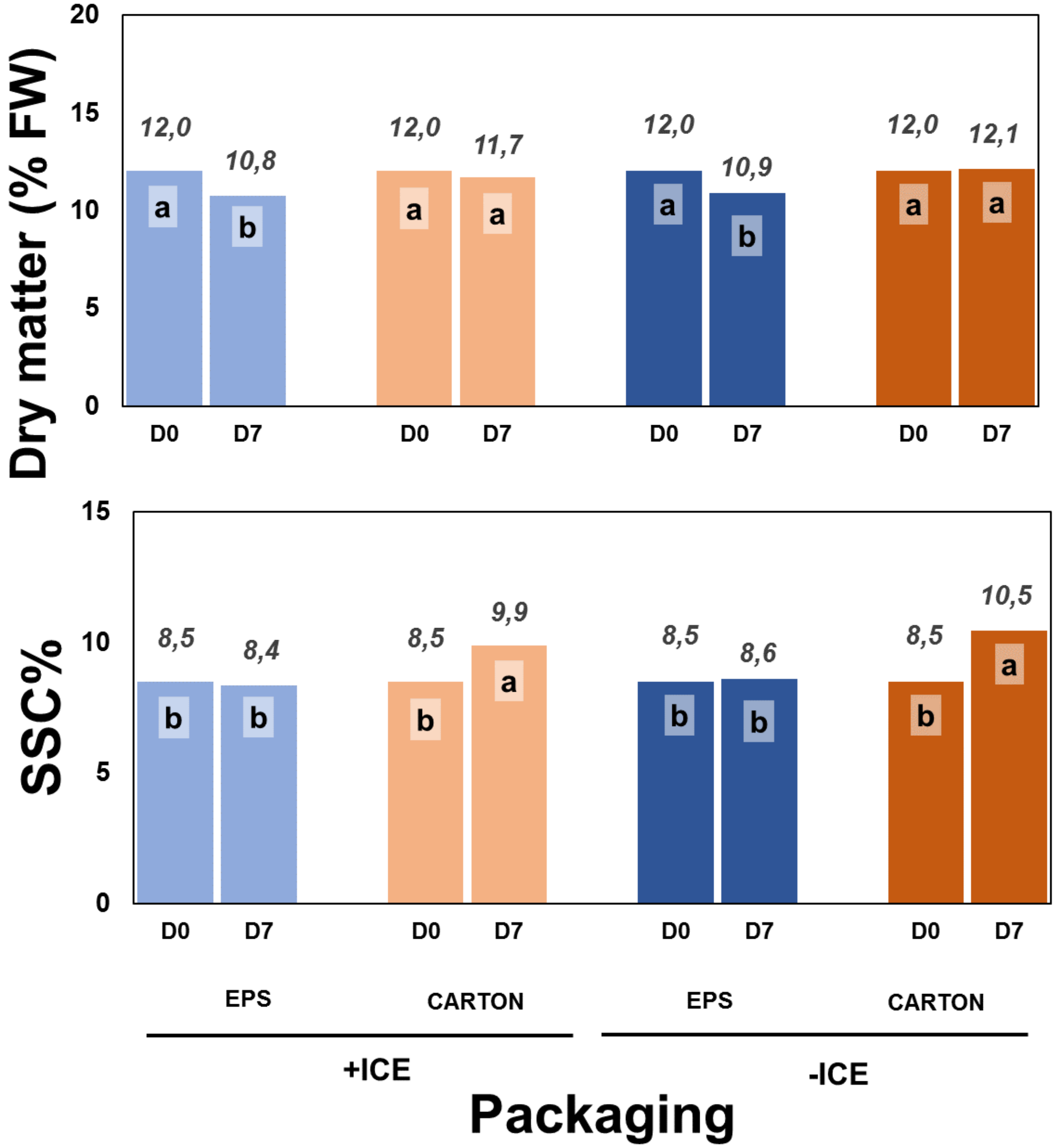


Figure 10. Dry matter and soluble solids content of broccoli florets stored at 15ºC for 0 and 7 days in EPS or carton boxes with or without ice addition. Different letters in the columns imply significant statistical differences among the means.

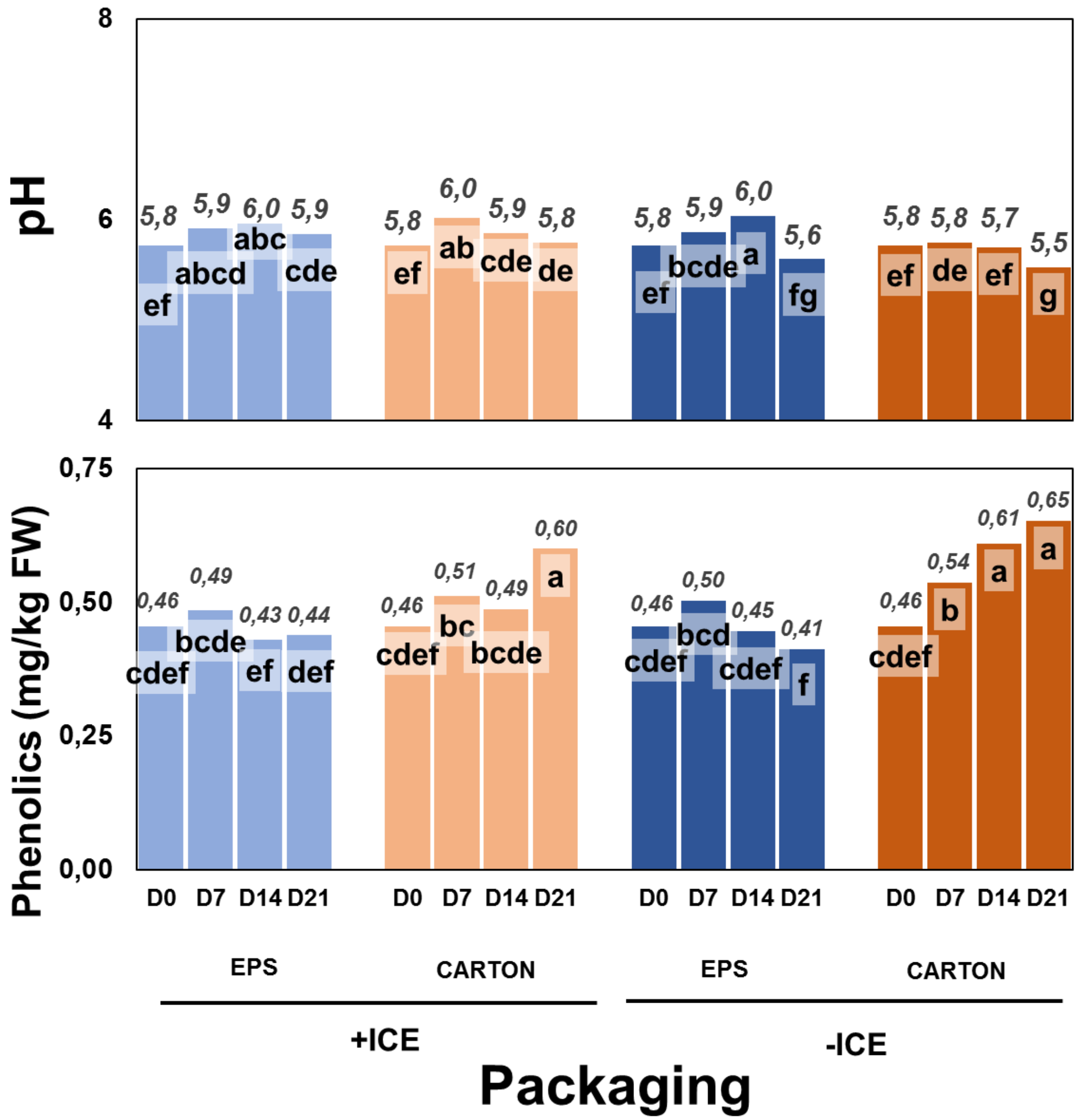


Figure 11. pH and soluble phenols content of broccoli florets stored at 5ºC for 0, 7, 14 and 21 days in EPS or carton boxes with or without ice addition. Different letters in the columns imply significant statistical differences among the means.

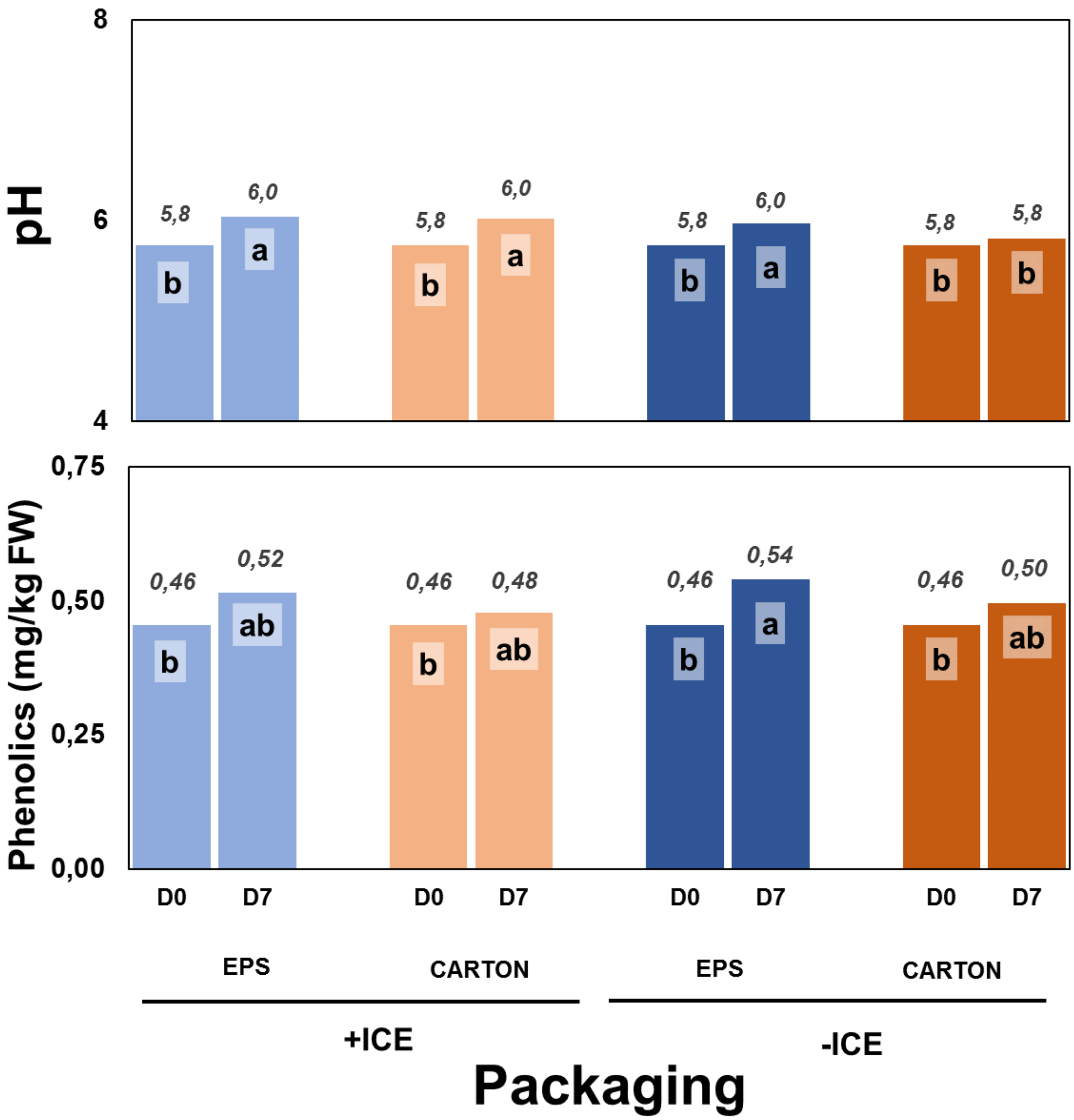


Figure 12. pH and soluble phenols content of broccoli florets stored at 15ºC for 0 and 7 days in EPS or carton boxes with or without ice addition. Different letters in the columns imply significant statistical differences among the means.

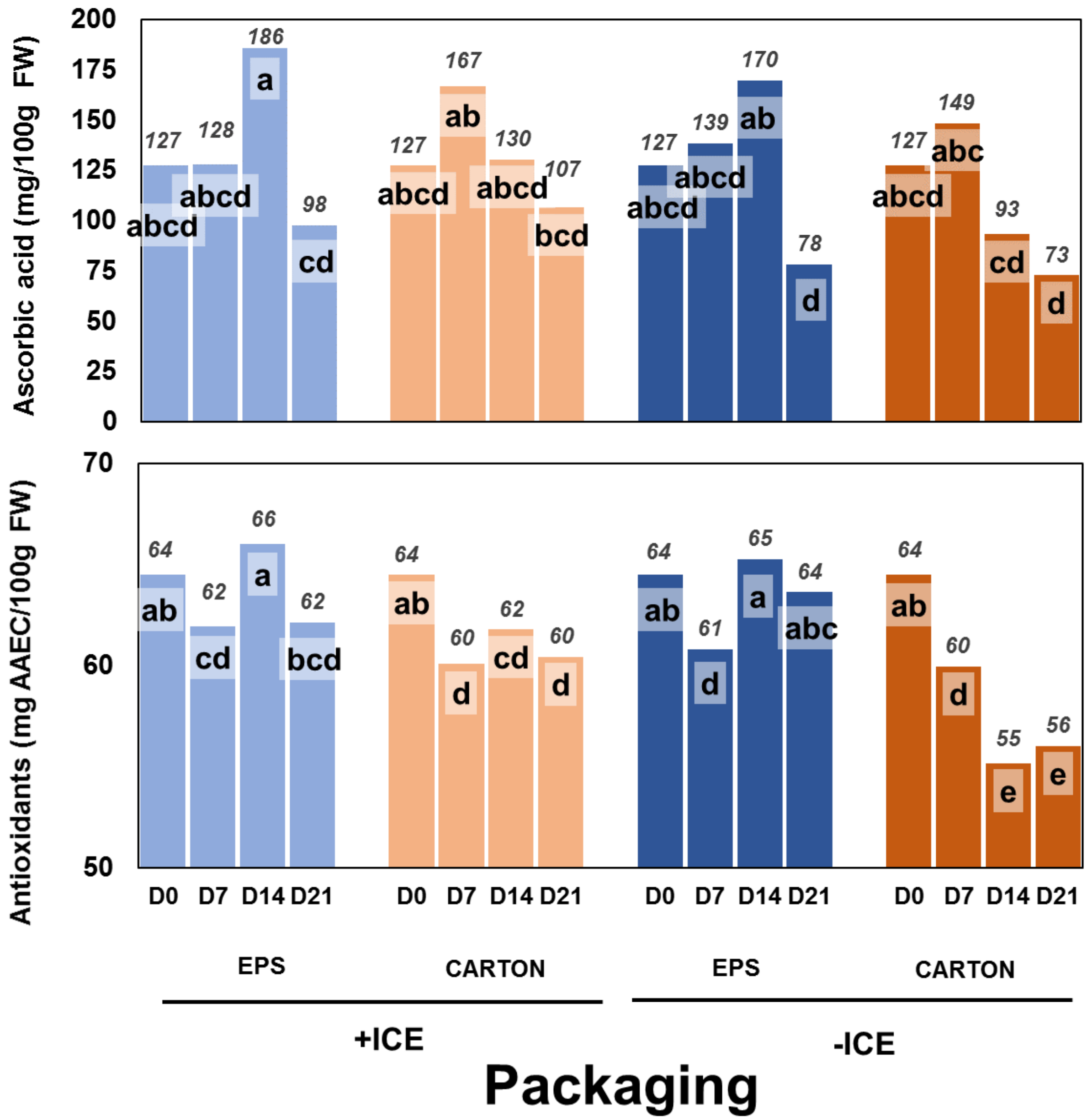


Figure 13. Ascorbic acid content and total antioxidant capacity of broccoli florets stored at 5°C for 0, 7, 14 and 21 days in EPS or carton boxes with or without ice addition. Different letters in the columns imply significant statistical differences among the means.

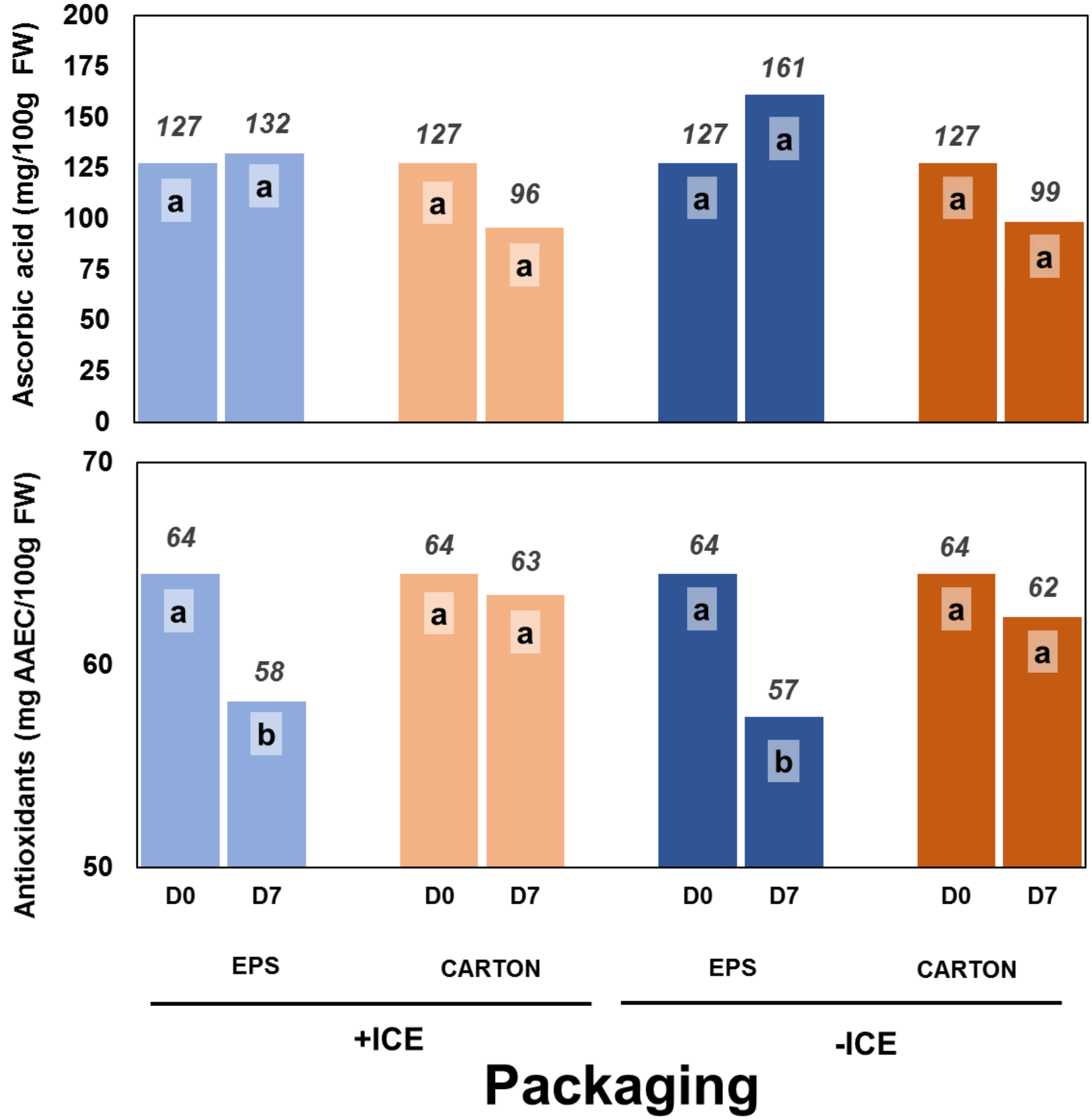


Figure 14. Ascorbic acid content and total antioxidant capacity of broccoli florets stored at 15°C for 0 and 7 days in EPS or carton boxes with or without ice addition. Different letters in the columns imply significant statistical differences among the means.

Report on Tomato Storage in EPS package

Abstract

Three hundred fifty tomato fruits were harvested from the commercial greenhouse of 'AGRIS SA' and were transferred within the same day in the Lab of Vegetable Crops, AUTH. Upon the arrival of fruits at the lab, they were immediately sorted in 3 distinct ripening stages, according to their color; in red (ripe stage), orange (mid-ripe stage) and green (immature stage). All the tomato fruits were weighed, had their color measured at two opposite sites on the equatorial zone and 9 of them were frozen immediately for analysis, representing Day 0 samples. The remaining tomato fruits of each one ripening stage were packaged either in EPS or corrugated carton boxes in 3 replicates, with 9 fruits per replication. All the tomato fruits in the EPS and corrugated carton fruit packing boxes were kept at 10^{o}C for one day to ensure a uniform temperature inside all packages. Data loggers were also placed inside the packages to record the temperature and the relative humidity conditions. The packages were transferred into two different storage temperatures, 10 and 20^{o}C. Every 5 days, three tomato fruits from each package were sampled. The weight and the color of each fruit were measured and they were frozen for nutritional composition analysis. The nutritional components determined were the dry matter, the pH, the titratable acidity, the total antioxidant capacity, as well as the total soluble solids, the total soluble phenols, the total carotenoids, the total chlorophyll, the b-carotene and lycopene content. Although at both storage temperatures, similar temperature levels were recorded inside the EPS packages and the corrugated carton boxes, the relative humidity was always maintained at higher levels with the lowest deviation in the EPS packages, due to the insulation that is offered by such a closed package system, in contrast to the open corrugated carton packages where a severe variation in the relative humidity was daily recorded. According to the results, it is concluded that the quality of the tomato fruits can be maintained in high level, during storage in EPS packaging systems, given that the fresh weight loss of tomatoes is as low as possible due to the reduced transpiration of the fruit in the closed EPS environment. At the same time, neither firmness nor color changes are greater in tomatoes placed in the EPS package, implying that such a packaging system offers an insulation as confirmed by the high relative humidity levels and its low fluctuation during storage, but at the same time permits the gas exchange with the external atmosphere and especially the escape of ethylene, which is considered as a gas ripening

hormone. Apart from the advantages of the use of EPS in the storage of tomatoes at both 10 and 20^{o}C, in maintaining the weight of the fruit, also the nutritional composition inside the tissue was not altered in a different way than fruits stored in uncovered carton boxes and particularly in terms of dry matter, soluble solids, titratable acidity, carotenoids, b-carotene, lycopene, phenolics and antioxidants. Summarizing the above, it is concluded that EPS packaging of tomatoes can ensure optimal quality preservation of tomatoes harvested either at the red ripe or even at the orange and green stage for a period of 15 days at 10 or 20^{o}C.

Materials and methods

Three hundred fifty tomato fruits (cv. Beef Bang) were harvested from the commercial greenhouse of 'AGRIS SA' and were transferred within the same day in the Lab of Vegetable Crops, AUTH. Upon the arrival of fruits at the lab, they were immediately sorted in 3 distinct ripening stages, according to their color; in red (ripe stage), orange (mid-ripe stage) and green (immature stage). All the tomato fruits were weighed, had their color measured at two opposite sites on the equatorial zone and 9 of them were frozen immediately for analysis, representing Day 0 samples. The remaining tomato fruits of each one ripening stage were packaged either in EPS or corrugated carton boxes in 3 replicates, with 9 fruits per replication. All the tomato fruits in the EPS and corrugated carton fruit packing boxes were kept at 10oC for one day to ensure a uniform temperature inside all packages. Data loggers were also placed inside the packages to record the temperature and the relative humidity conditions. The packages were transferred into two different storage temperatures, 10 and 20oC. Every 5 days, three tomato fruits from each package were sampled. The weight and the color of each fruit were measured and they were frozen for nutritional composition analysis. The nutritional components determined were the dry matter, the pH, the titratable acidity, the total antioxidant capacity, as well as the total soluble solids, the total soluble phenols, the total carotenoids, the total chlorophyll, the b-carotene and lycopene content.

Results

Temperature and relative humidity

The temperature in both EPS and carton packages remained steady at 10 °C and quickly rose from 10 to 20°C, after being transferred to the high storage temperature (Fig. 15&16).

At both storage temperatures, no difference between EPS packages and corrugated carton boxes was recorded. Apparently, the great void volume in the package and the low respiration rate of tomato fruits prevented from the increase of air temperature in EPS. The mean temperatures recorded in the packages that were stored at 10 and 20°C, respectively, were: 10.8 and 19.8°C in EPS package and 10.5°C and 19.8°C in corrugated carton package, respectively, without significant variation from the average value, as indicated by the very low standard errors (<0.72°C).

The relative humidity was more stable in the EPS packages that were stored at 10°C (Fig. 17), followed by EPS packages at 20°C (Fig. 18), while in the corrugated carton package, severe variation in the relative humidity was observed either at 10 or 20°C (Fig 17&18). Higher relative humidity variation was observed at the 10°C storage temperature in the open carton boxes, due to the continuous circulation of the air by the cooling, and in turn this last one contributed to the dehydration of the tomatoes placed in the corrugated carton package, resulting in a higher weight loss.

The average relative humidity levels recorded in the packages that were stored at 10°C was as high as 98.7% in EPS package stored at 10°C with a very low deviation (±1.2%), followed by corrugated carton package (92%) (Fig 17&18). EPS packaging preserved a high RH level (87.7%) during storage at 20°C whereas the relative humidity recorded in the same temperature from data loggers placed in the corrugated carton packages revealed an extremely low average RH (64.7%) with a notably high deviation (11.2%) (Fig, 18). Generally, the daily relative humidity fluctuated severely during each day at 10°C and was very low in 20°C, with both conditions not be considered as ideal in postharvest storage of tomato fruits.

Weight loss

The weight loss of the tomato fruits is attributed to the respiration and transpiration processes that take place during storage. Both respiration and transpiration rates depend strongly on the storage temperature and perhaps even more to the relative humidity of the surrounding area of the tomatoes.

Tomatoes harvested at the red ripe stage and stored in EPS packages at 10°C lost 0.3, 0.6 and 0.8% of their initial weight after 5, 10 and 15 days of storage, respectively (Fig. 19). Tomatoes harvested at the orange stage and stored in the above conditions (EPS, 10°C) lost 0.4-0.9% weight (Fig. 20), whereas the weight loss of fruits that were harvested at the green stage reached 0.4- 1.0% after two weeks of storage at 10°C in the EPS packaging (Fig. 21). Tomatoes harvested at the red, orange and green stage and packaged in open corrugated carton boxes suffered from significantly higher weight loss, comparing with the EPS packages ones, resulting in 1.3, 1.6 and 1.9% after 15 days of storage at 10°C (Figs. 19-21). Storage of tomatoes in increased (room) temperature, 20oC, significantly enhanced weight loss of tomato fruits harvested at all 3 different ripening stages, but was always higher, from 50 to 119%, greater in carton packages comparing to the corresponding fruits that were stored in EPS (Figs 19-21).

Firmness

The firmness of tomatoes harvested at the red ripe stage was 1.14 kg, those at the orange stage were 1.55 kg firm, whereas the green fruits had an even higher firmness of 1.93 kg (Figs. 22-24). Storage at 20°C mostly affected orange and green stage harvested tomatoes. Indeed, fruits harvested at the red stage slightly softened during storage at either 10 or 20°C after 2 weeks of storage, reaching 0.84-1.02 kg, without significant differences either among the two storage temperatures or between the two packages (Figs 22-24). On the other hand, orange and green stage harvested fruits reached 0.81-0.95 kg firmness, significantly lower than storage at 10°C, but without notable differences between EPS or conventional carton packages.

Color

The color of the tomato fruits was measured on the equatorial zone of each fruit, with a Minolta CR-200 colorimeter. Different color parameters were determined, namely lightness (L*), chroma (C*) and hue angle (h°).

Lightness (L*) describes the brightness of a tissue and takes values between 0 that corresponds to black color and 100 that corresponds to white. Lightness was lower in the red ripe fruits, comparing to orange and green ones, but only slightly changed during storage with no significant differences in fruits packaged in EPS or carton box or between the tomatoes stored in 10 or 20^oC (Figs 25-27).

Chroma (C*) represents the vividness (high values) or dullness (low values) of a color. During two weeks of storage at 10^oC, C* values increased in all fruits and as a result even the tomatoes that were harvested at the green stage finally obtained the C* values that the red ripe fruits initially had (Fig. 28-30). Indeed, it is worth mentioning that fruits packaged in EPS always had significantly higher C* values than the ones that were placed in open carton box, implying an advance ripening process perhaps due to the presence of a low amount of ethylene inside the EPS package. During storage at 20^oC, chroma of orange and green tomatoes increased substantially with the first 5 days of storage and only slightly thereafter, without significant differences between the two packages (Figs. 28-30).

Hue angle describes the hue of the color and each degree corresponds to a specific color (0^o for red, 90^o for yellow, 180^o for green, 270^o for blue). Hue angle was lowest at the red ripe tomatoes and highest at the green ones (Figs. 31-33). During storage at both temperatures, hue angle values decreased in orange and green fruits, but it never became as low as the red ripe tomatoes even after 15 days, implying an incomplete ripening of these tomatoes (Fig. 30). However, storage at 20^oC induced an advance ripening process of all tomatoes, implying that after 2 weeks, all tomatoes were of the same red color (Figs 31-33), as also confirmed by the photos 11-15. No significant differences were found between EPS and carton packages.

Nutritional quality

Total soluble solids content (SSC) includes all sugars and organic acids that are responsible for the flavor in vegetables. At harvest SSC was 4.72, 4.97 and 5.03% in red ripe, orange and green tomatoes, respectively and were showed only minimal variation during storage without dropping lower than 4.43% (Fig. 34-36).

Dry matter of tomatoes from all ripening stages at harvest was 5.2-5.4% and was not affected during storage either by the temperature or by the packaging system (EPS or open carton box), remaining almost unchanged up to 15 days of storage (Figs. 37-39).

During the two weeks of storage, pH of tomato fruits was fluctuating from 4.0- 4.3, without significant differences either between the two temperatures or the two packages, irrespectively of the ripening stage at harvest (Figs. 40-42). In all cases, 0.3 units of pH change cannot be considered as a significant nutritional change and neither can be perceived by humans during consumption.

Titratable acidity (TA) is an index of organic acids concentration in tomato flesh, with high values often being associated with sourness of the fruit. Lower TA (0.07%) was observed in red ripe tomatoes, as anticipated, not being substantially different after 15 days of storage at both temperatures and packaging systems (Fig. 43). The pH of orange tomatoes decreased during storage at both temperatures without differences between EPS and corrugated carton box (Fig. 44). On the other hand, although a decrease of pH was also observed in tomatoes harvested at the green and stored in 10 or 20^{o}C, it never obtained the low values of red ripe tomatoes after two weeks, irrespectively or being packaged in EPS or carton box (Fig. 45).

Regarding the ratio soluble solids content/ titratable acidity (SSC/TA), which is an index of the human sense of the flavor of the tomato fruit, changes during storage were only observed in orange and green harvested tomatoes which can be explained by the increase of reducing sugars and the reduction of organic acids content (46-48). No significant differences between the EPS and open carton package were found in both storage temperatures.

Total chlorophylls decreased (data not shown) and carotenoids increased (Figs. 49-51) significantly especially in fruits of all three ripening stages stored at 20^{o}C, without notable differences between the ones placed in EPS or open corrugated carton boxes.

The increase of total carotenoid content was following the increase of lycopene content (Figs. 52-54) and b-carotene (Figs. 55-57), which are the two principal carotenoids that contribute to the total content. As anticipated, no difference between EPS and carton packages was found.

Phenols content was 0.20 μg gallic acid equivalents/ g fresh weight at harvest, not different between the three ripening stages and slightly decreased in all fruits stored at both temperatures and packages (Figs. 58-60).

The same pattern with total soluble phenols content was found in the antioxidant capacity of fruits, that was also slightly decreased but without being different between fruits of the two packaging systems (Figs. 61-63).

Conclusions

According to the above results, it is concluded that the quality of the tomato fruits can be maintained in high level, during storage in EPS packaging systems, given that the fresh weight loss of tomatoes is as low as possible due to the reduced transpiration of the fruit in the closed EPS environment. At the same time, neither firmness nor color changes are greater in tomatoes placed in the EPS package, implying that such a packaging system offers an insulation as confirmed by the high relative humidity levels and its low fluctuation during storage, but at the same time permits the gas exchange with the external atmosphere and especially the escape of ethylene, which is considered as a gas ripening hormone. Apart from the advantages of the use of EPS in the storage of tomatoes at both 10 and 20^{o}C, in maintaining the weight of the fruit, also the nutritional composition inside the tissue was not altered in a different way than fruits stored in uncovered carton boxes and particularly in terms of dry matter, soluble solids, titratable acidity, carotenoids, b-carotene, lycopene, phenolics and antioxidants. Summarizing the above, it is concluded that EPS packaging of tomatoes can ensure optimal quality preservation of tomatoes harvested either at the red ripe or even at the orange and green stage for a period of 15 days at 10 or 20^{o}C.

Photo 8. Tomato fruits harvested from Agris SA greenopuse and immediately transferred to the facilities of the Lab of Vegetable Crops, AUTH.

Photo 9. Tomato fruits sorted in 3 distinct ripening stages (red ripe, orange and green) after they were transferred to the Lab of Vegetable Crops.

Photo 10. Packaging of tomatoes in expanded polystyrene (EPS) or corrugated carton boxes, according to the ripening stage of the fruits.

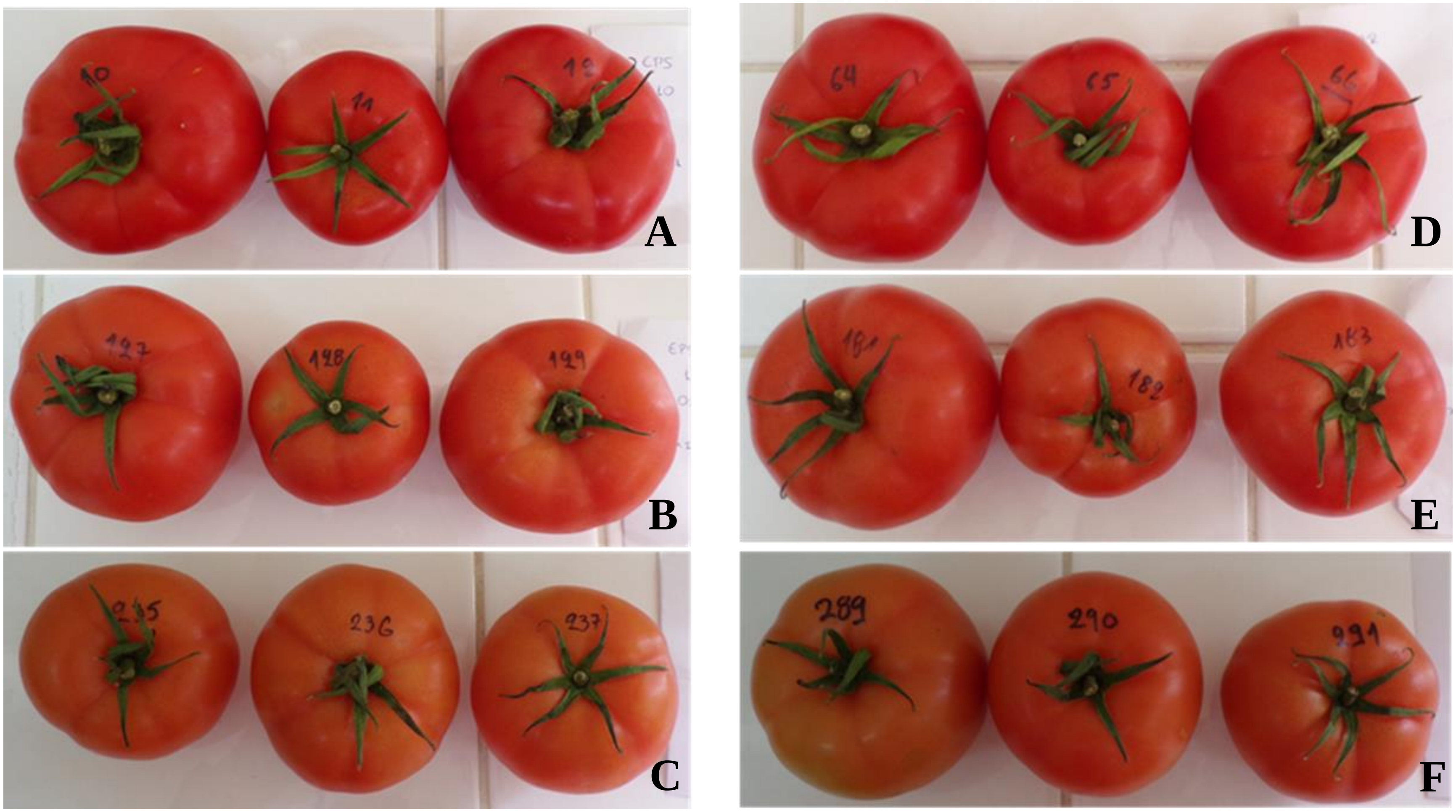


Photo 11. Tomato fruits harvested at the red ripe (A, D), orange (B, E) and green (C, F) stage and stored at 10^{o}C in EPS (A-C) or carton box (D-F) for 1 week.

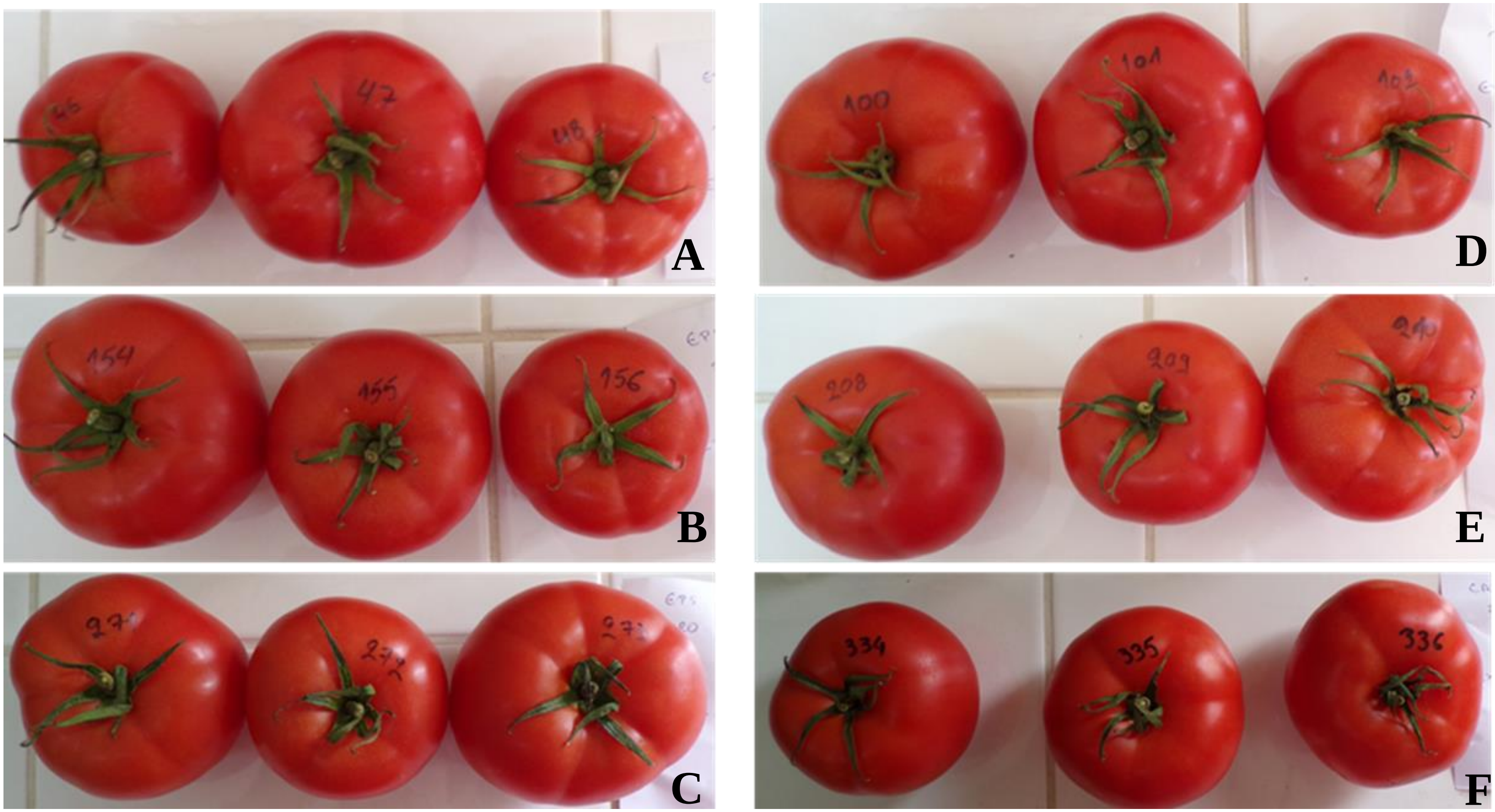


Photo 12. Tomato fruits harvested at the red ripe (A, D), orange (B, E) and green (C, F) stage and stored at 20ºC in EPS (A-C) or carton box (D-F) for 1 week.

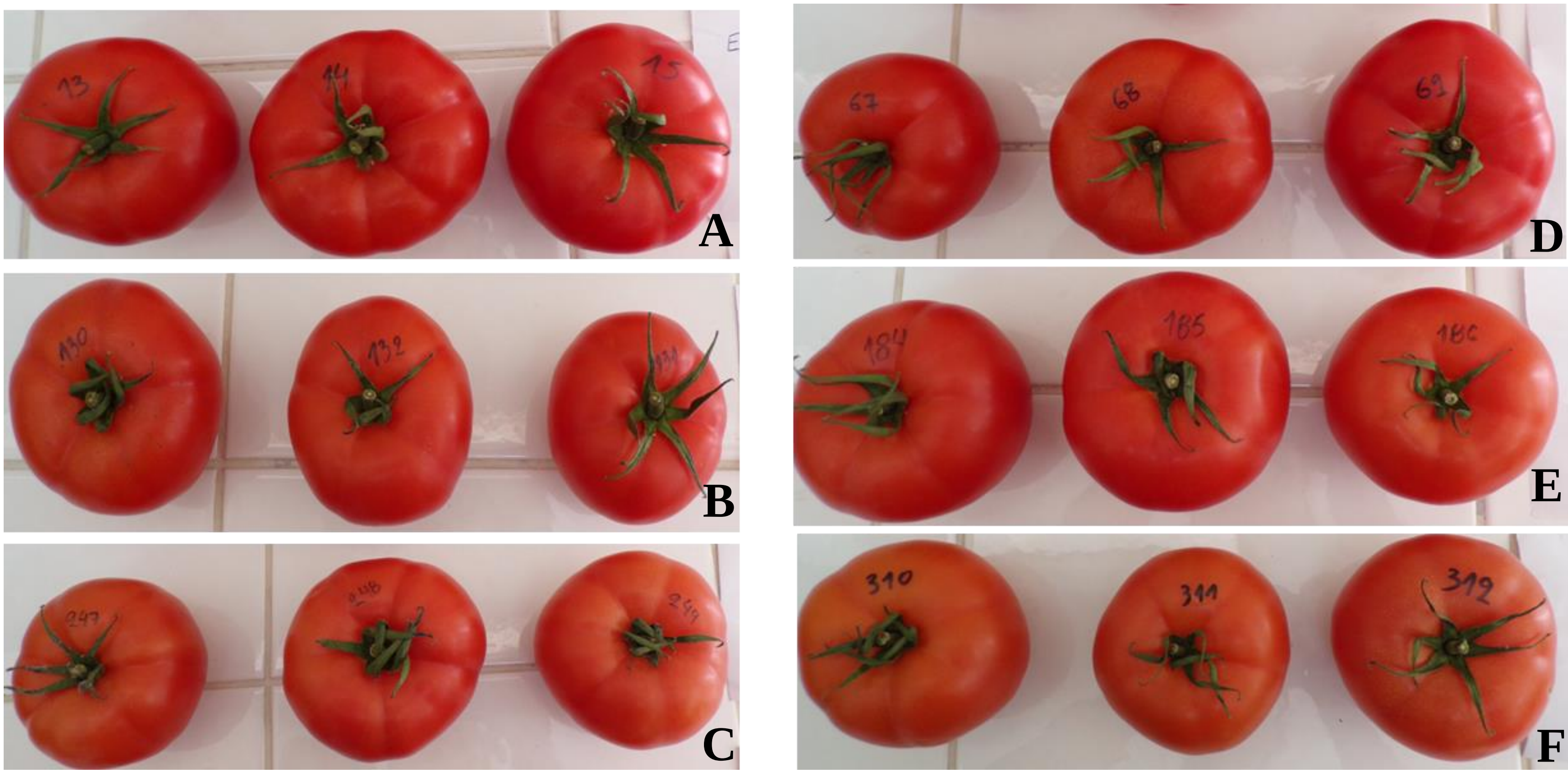


Photo 13. Tomato fruits harvested at the red ripe (A, D), orange (B, E) and green (C, F) stage and stored at 10^{o}C in EPS (A-C) or carton box (D-F) for 1 week.

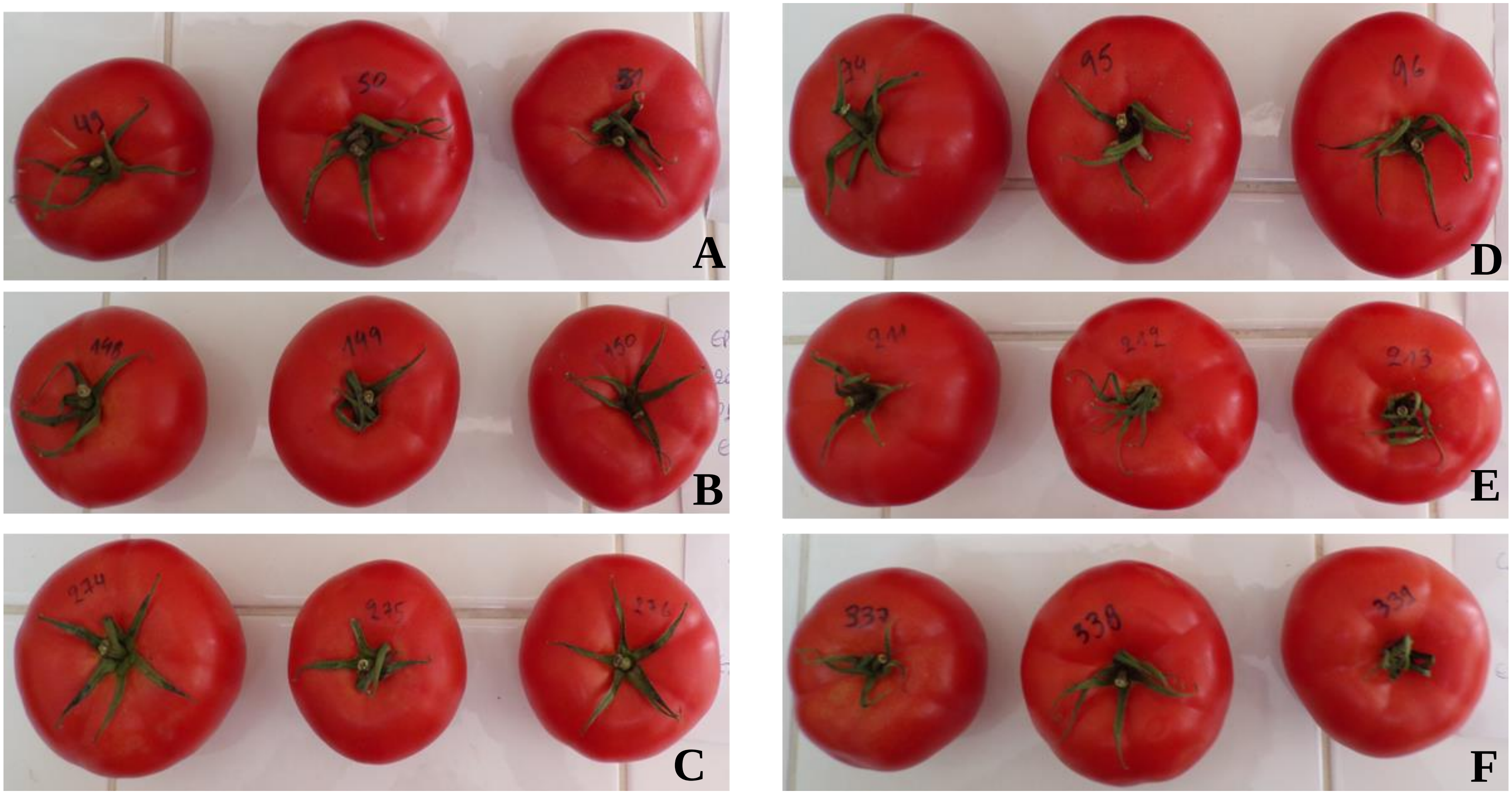


Photo 14. Tomato fruits harvested at the red ripe (A, D), orange (B, E) and green (C, F) stage and stored at 20^{o}C in EPS (A-C) or carton box (D-F) for 2 weeks.

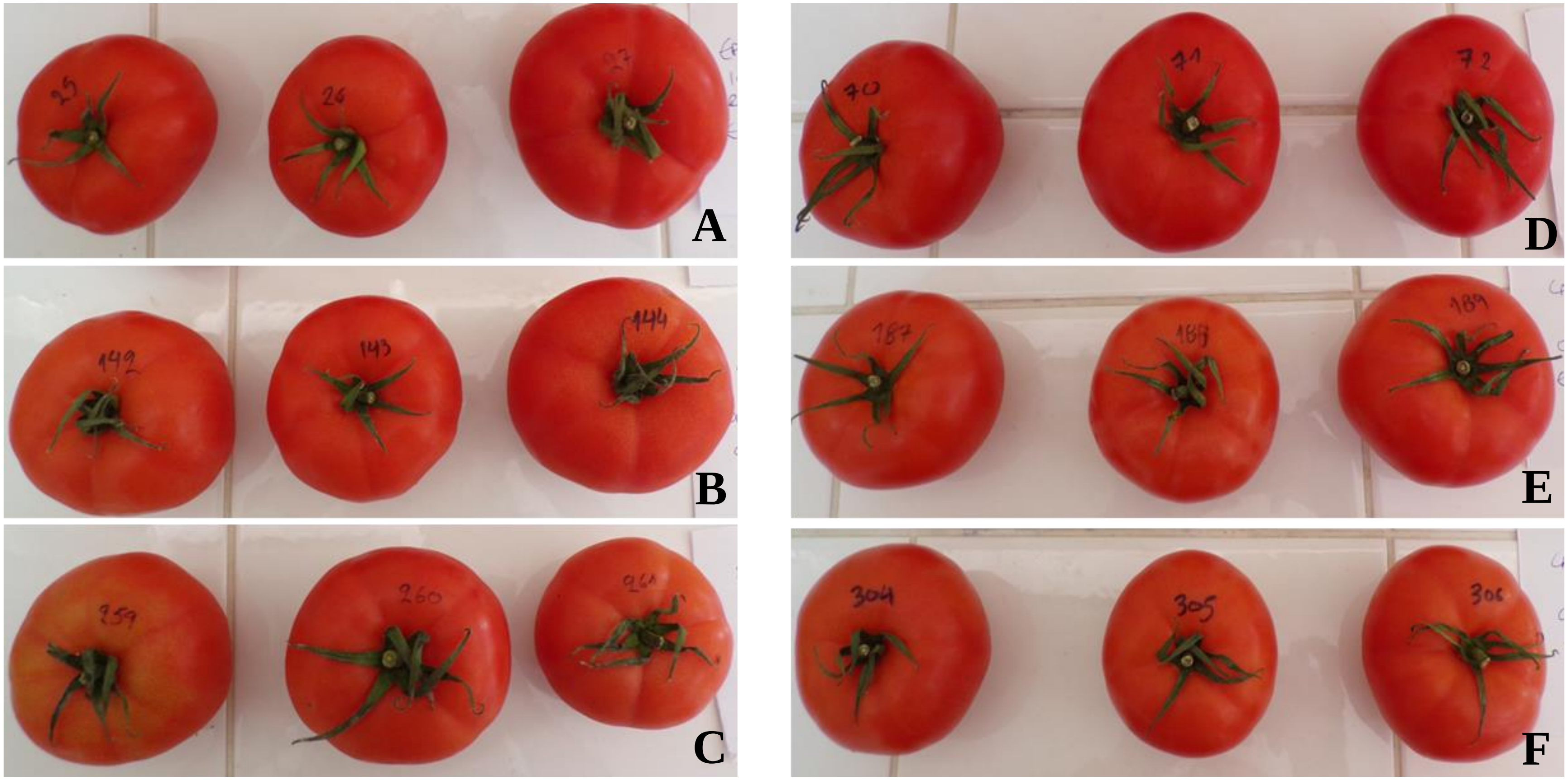


Photo 15. Tomato fruits harvested at the red ripe (A, D), orange (B, E) and green (C, F) stage and stored at 10^{o}C in EPS (A-C) or carton box (D-F) for 3 weeks.

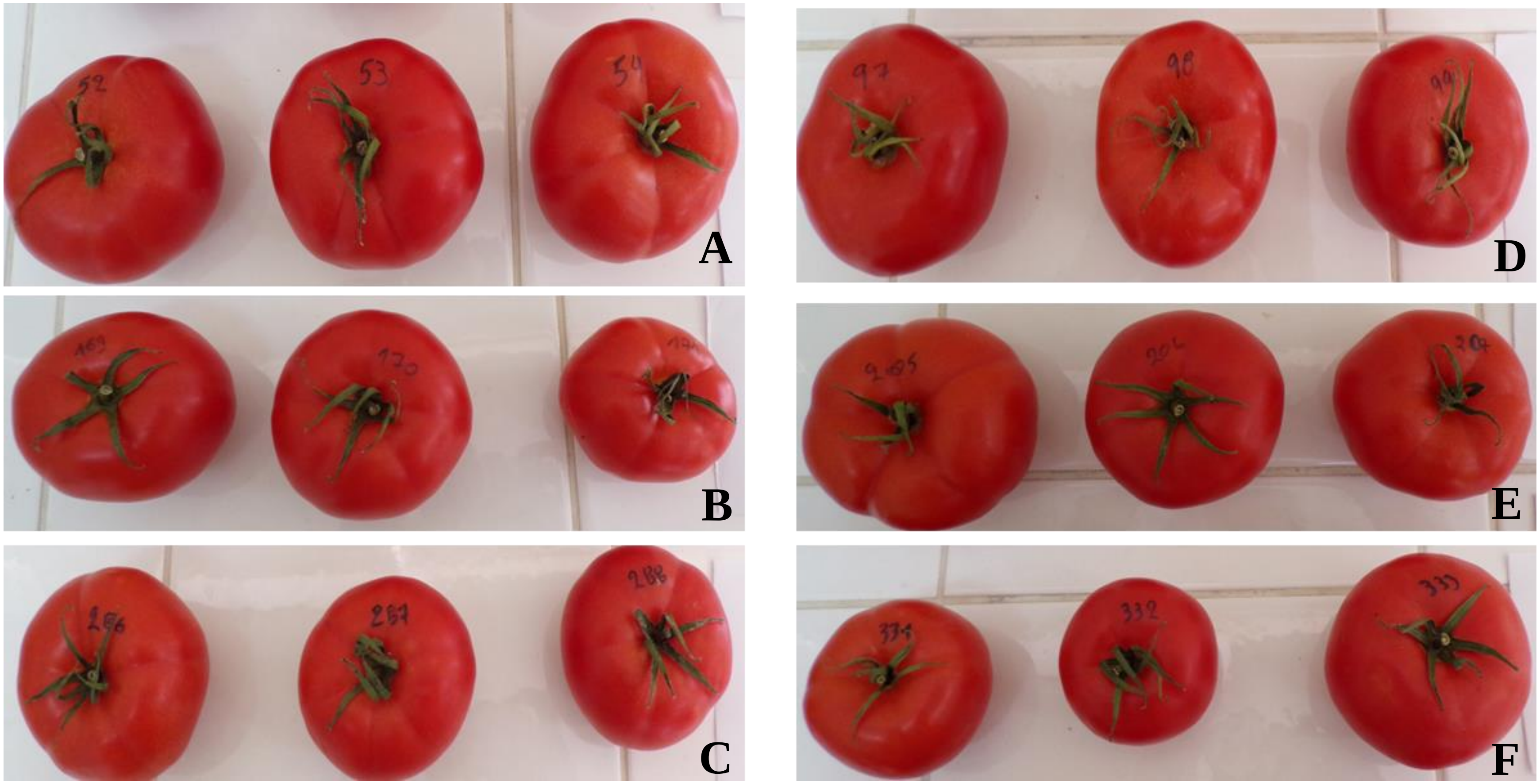


Photo 15. Tomato fruits harvested at the red ripe (A, D), orange (B, E) and green (C, F) stage and stored at 20°C in EPS (A-C) or carton box (D-F) for 3 weeks.

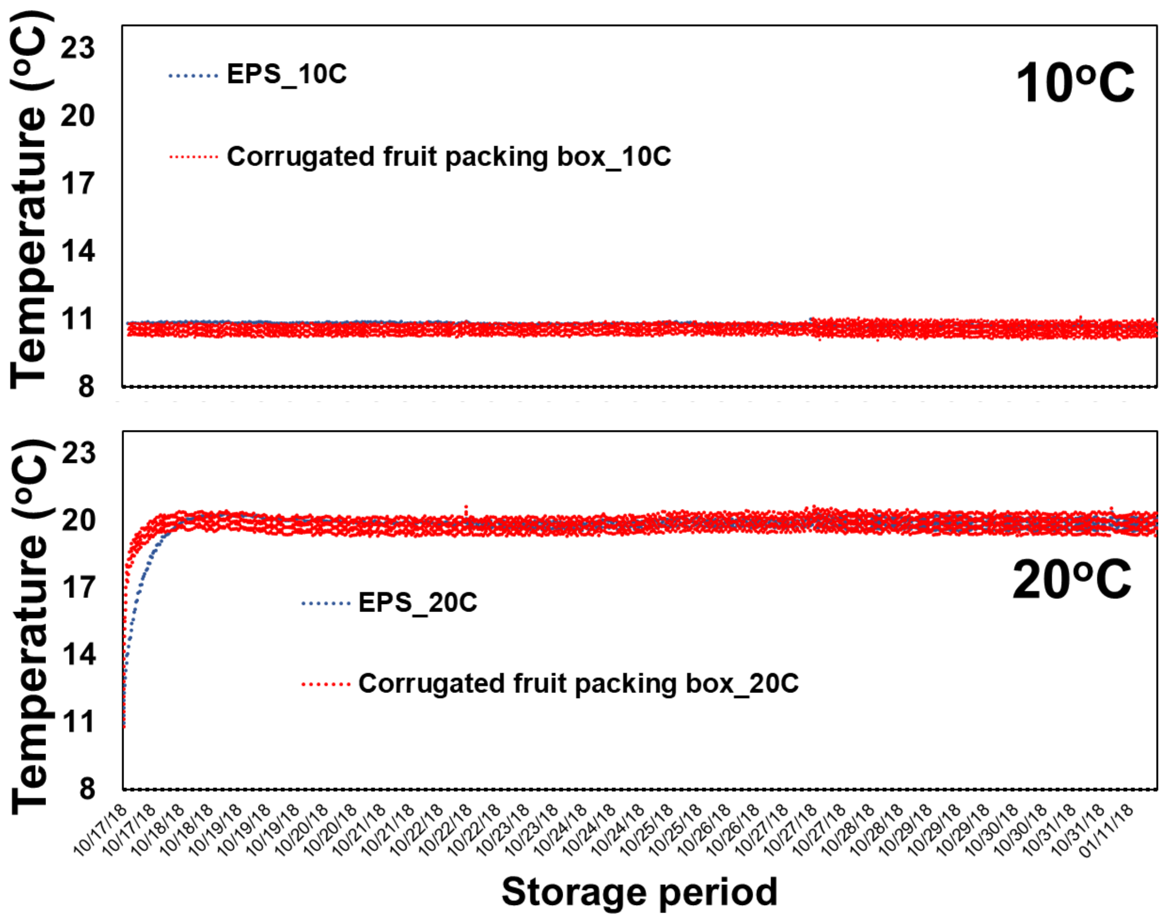


Figure 15. Temperature inside the EPS and the corrugated carton boxes of tomato fruits at 10 and 20ºC during storage.

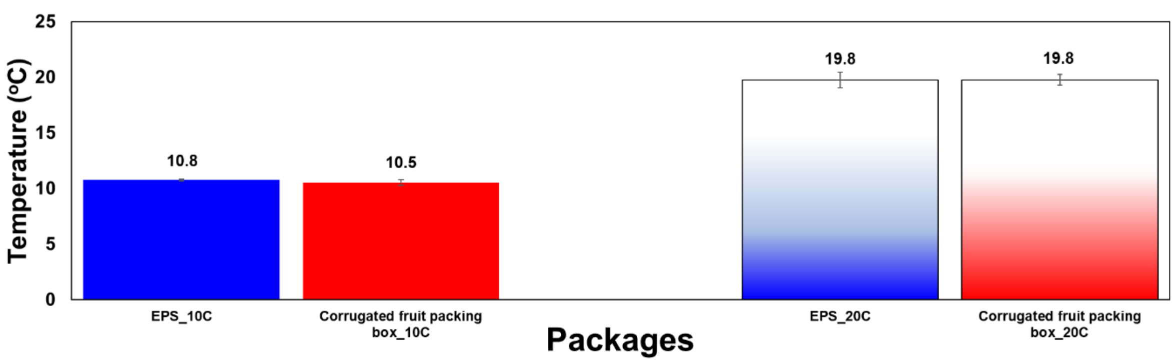


Figure 16. Mean temperature (± S.E.) inside the EPS and the corrugated carton boxes of tomato fruits at 10 and 20ºC during the whole period of storage.

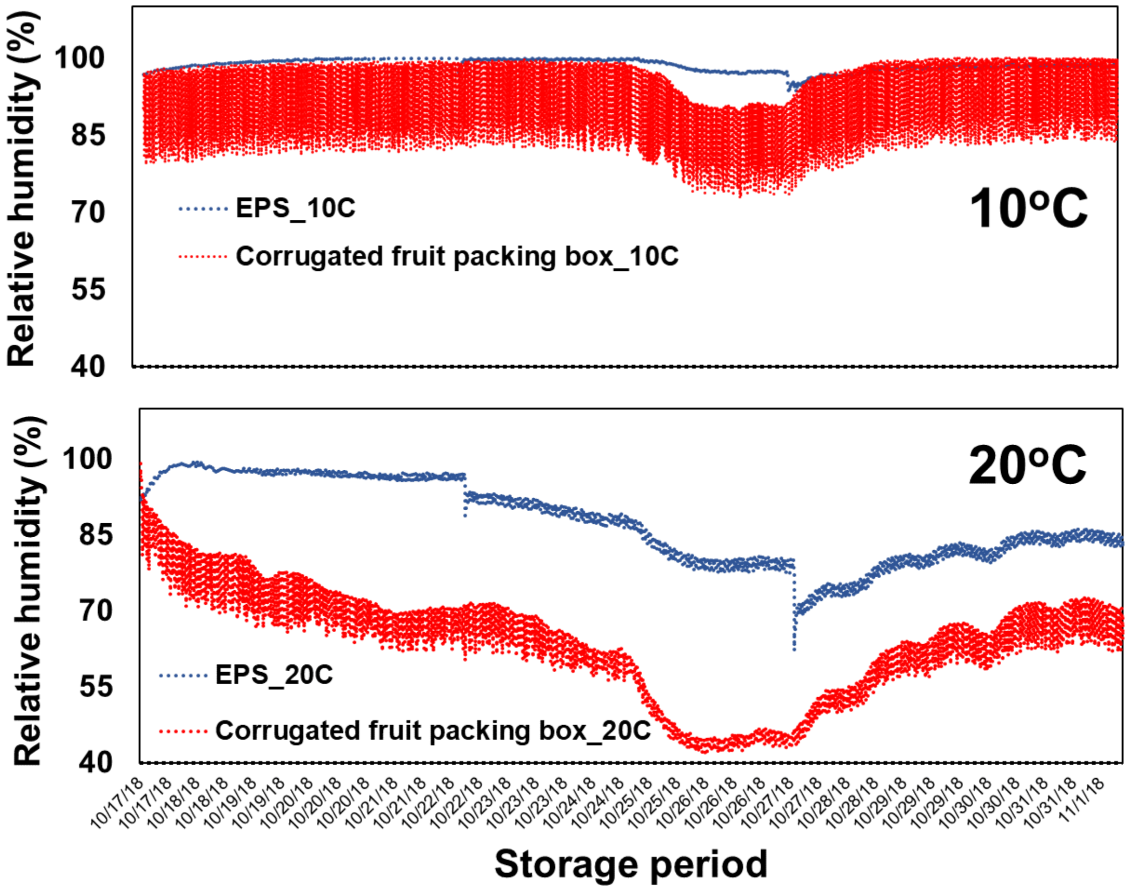


Figure 17. Relative humidity inside the EPS and the corrugated carton boxes of tomato fruits at 10 and 20ºC.

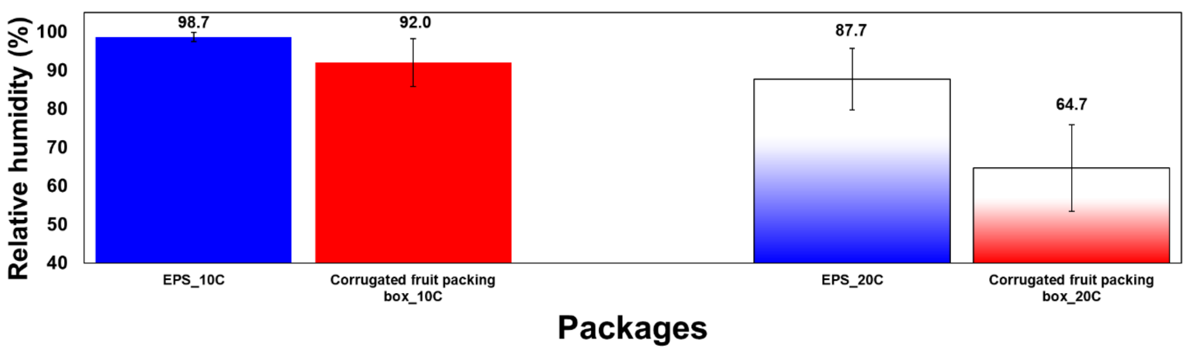


Figure 18. Mean relative humidity (± S.E.) inside the EPS and the corrugated carton boxes of tomato fruits at 10 and 20ºC during the whole period of storage.

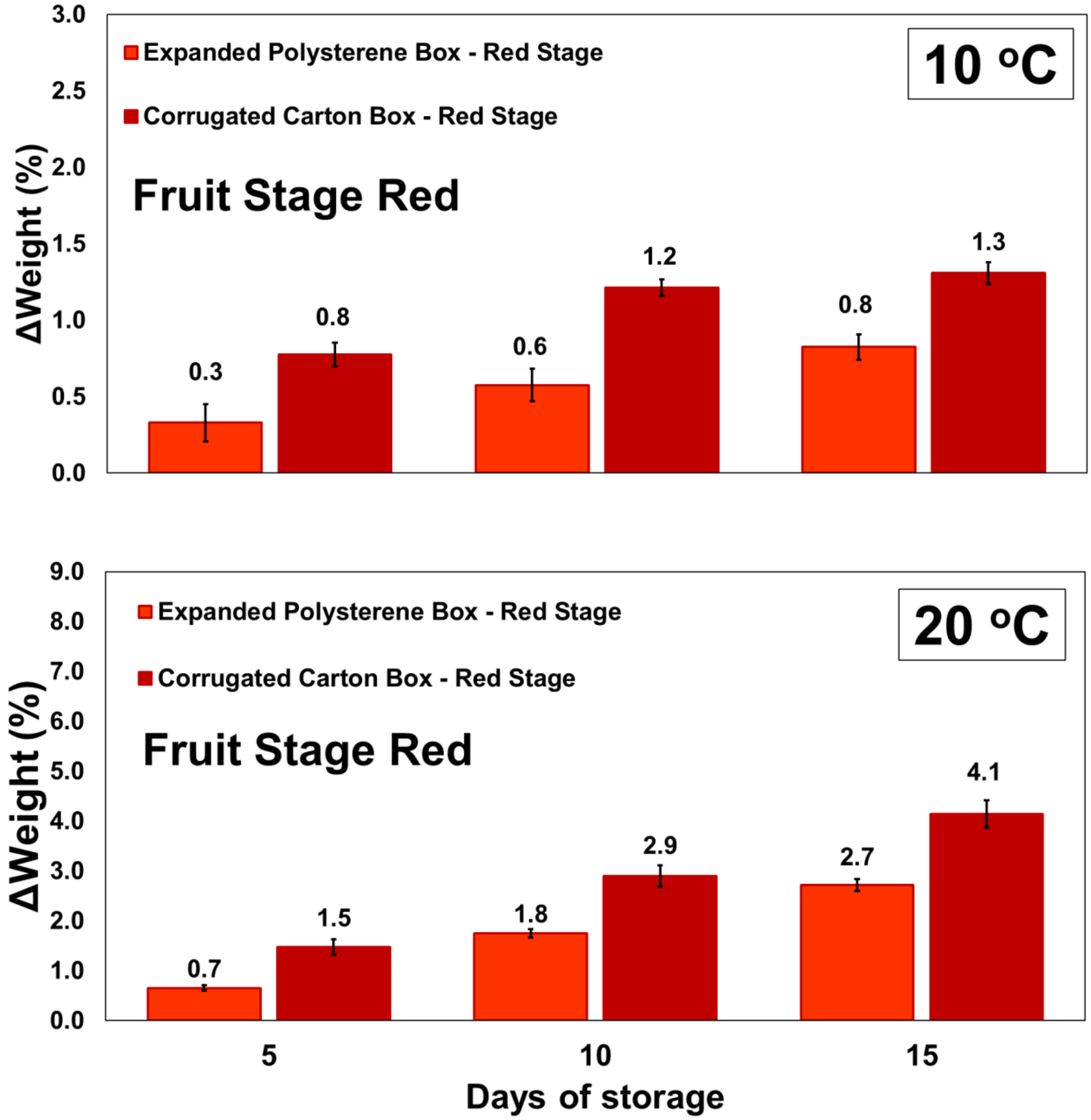


Figure 19. Δweight (%) (± S.E.) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20^{o}C for 5, 10 and 15 days.

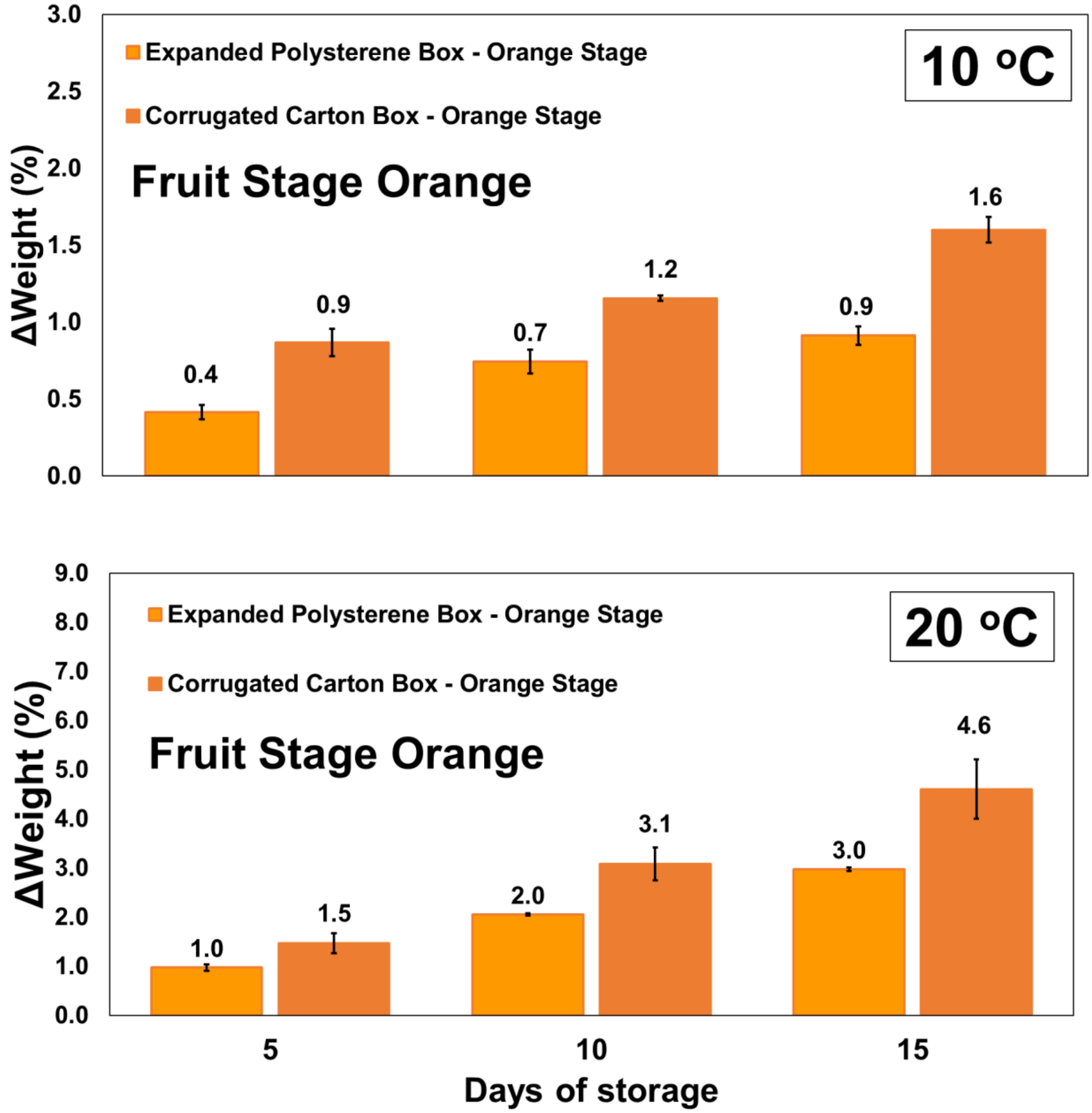


Figure 20. Δweight (%) (± S.E.) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

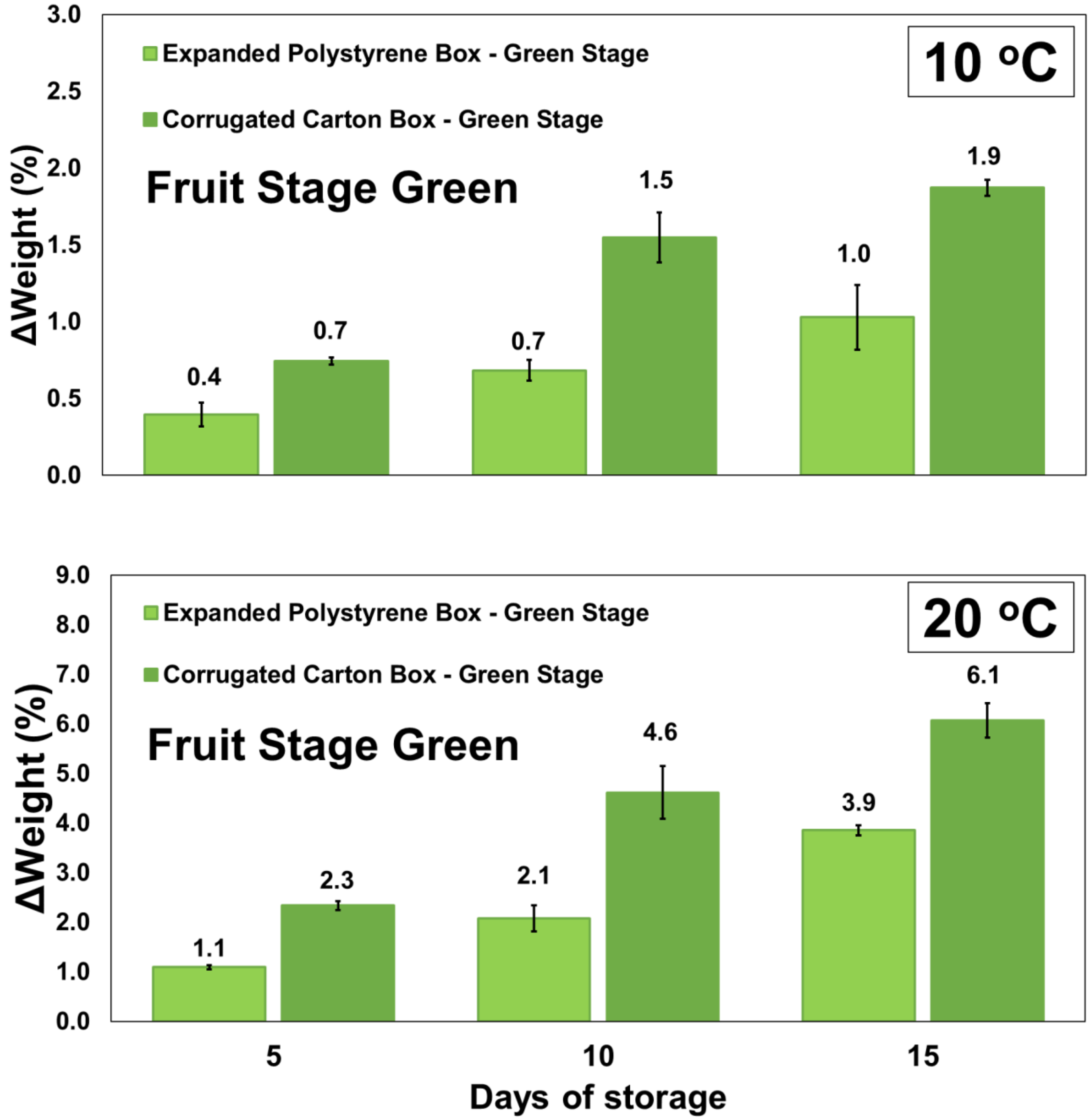


Figure 21. Δweight (%) (± S.E of tomato fruits harvested at the green stage and stored .) inside the EPS and the corrugated carton boxes at 10 and 20ºC for 5, 10 and 15 days.

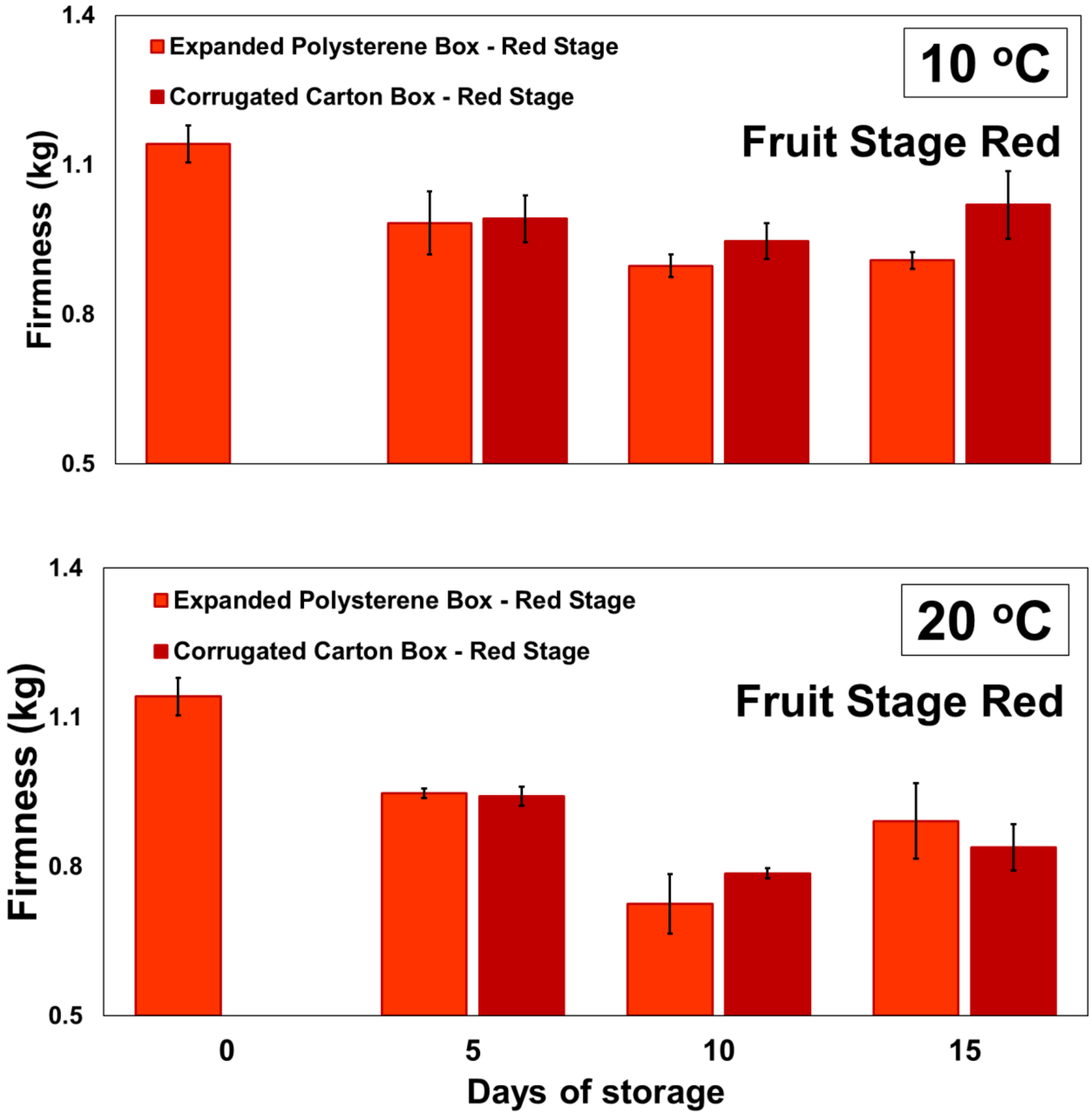


Figure 22. Firmness (kg) (± S.E.) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

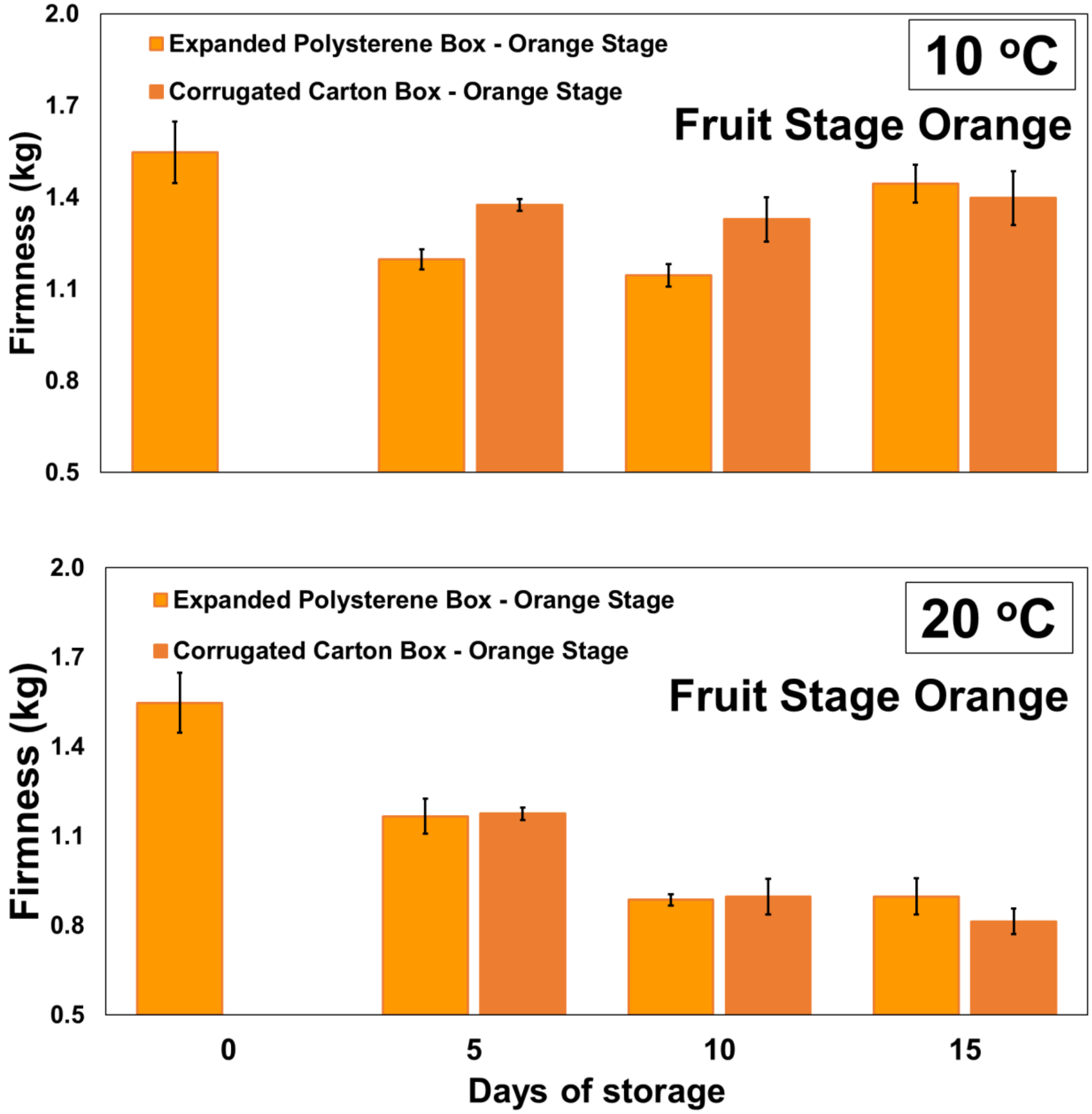


Figure 23. Δweight (%) (± S.E.) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

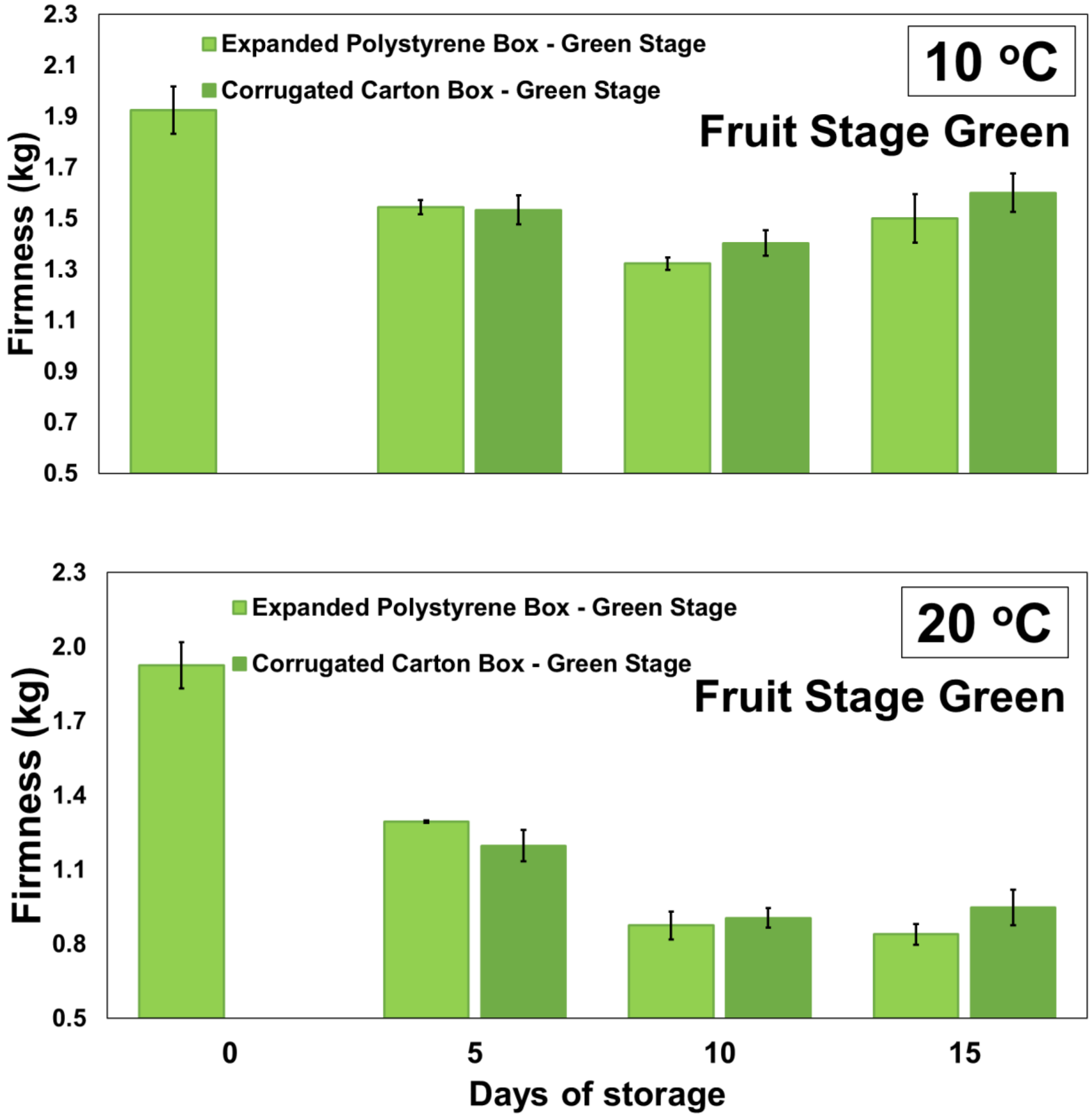


Figure 24. Δweight (%) (± S.E.) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

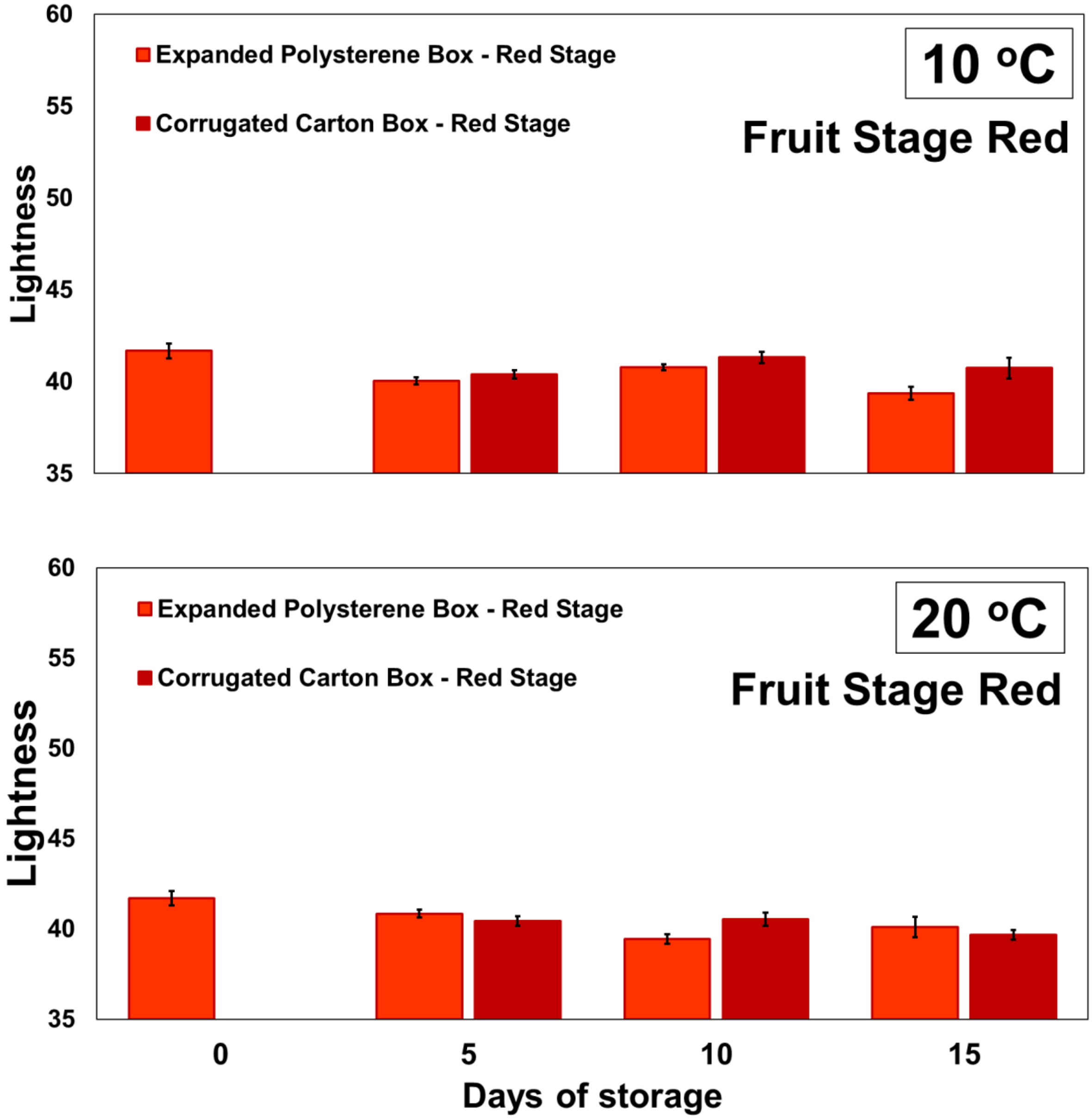


Figure 25. Lightness (± S.E.) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20^{o}C for 5, 10 and 15 days.

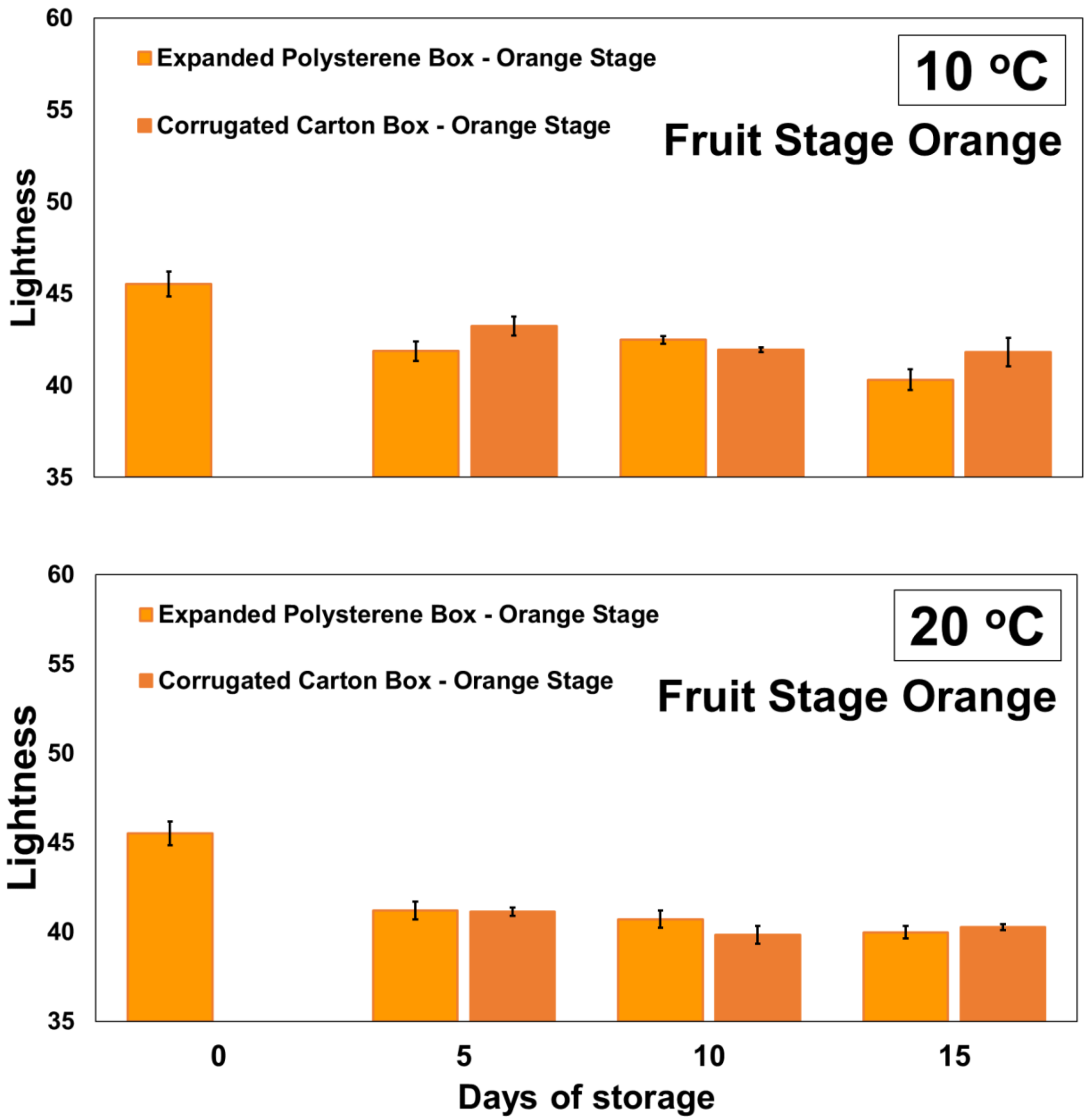


Figure 26. Lightness (± S.E.) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 5, 10 and 15 days.

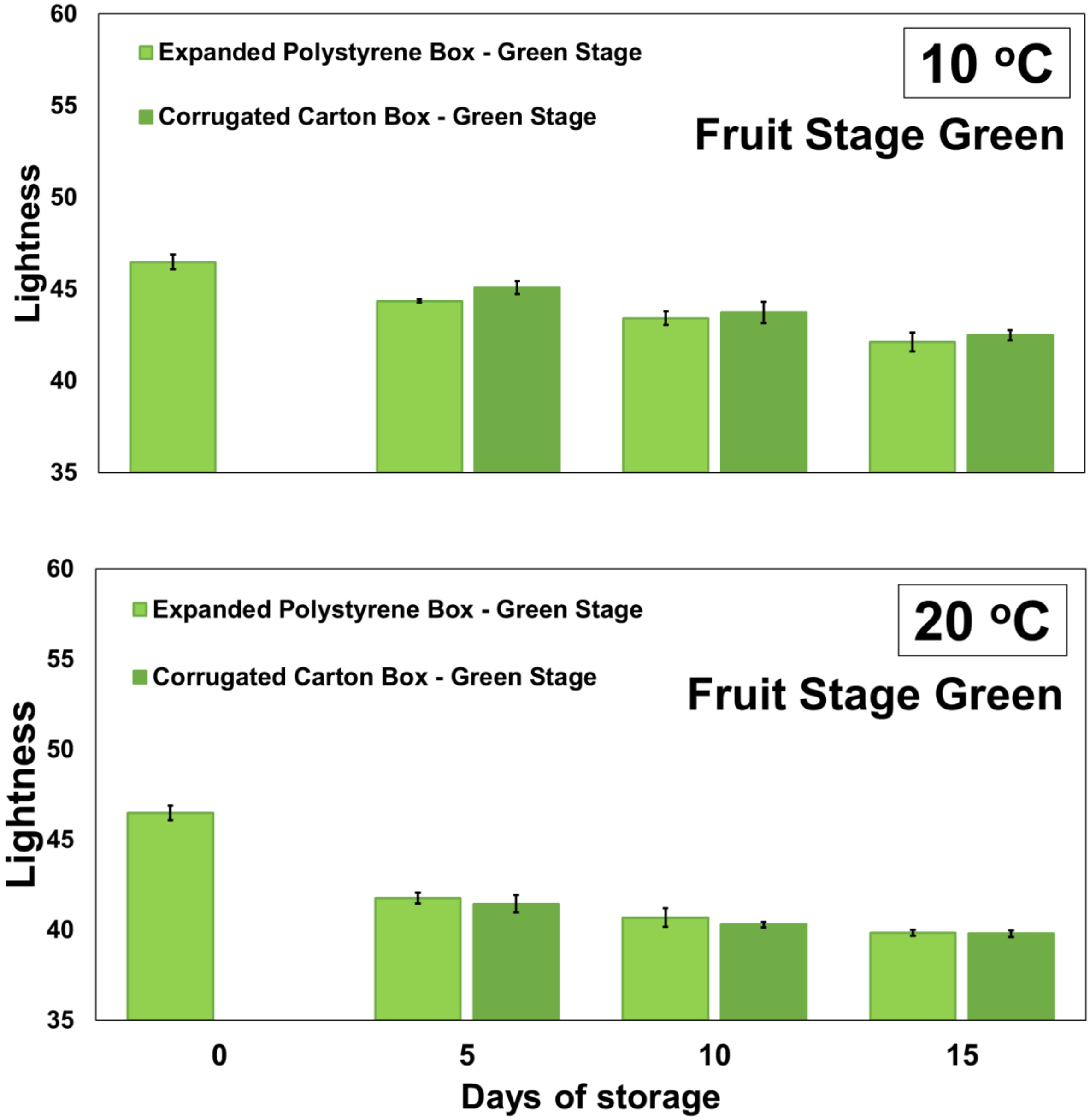


Figure 27. Lightness (± S.E.) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 5, 10 and 15 days.

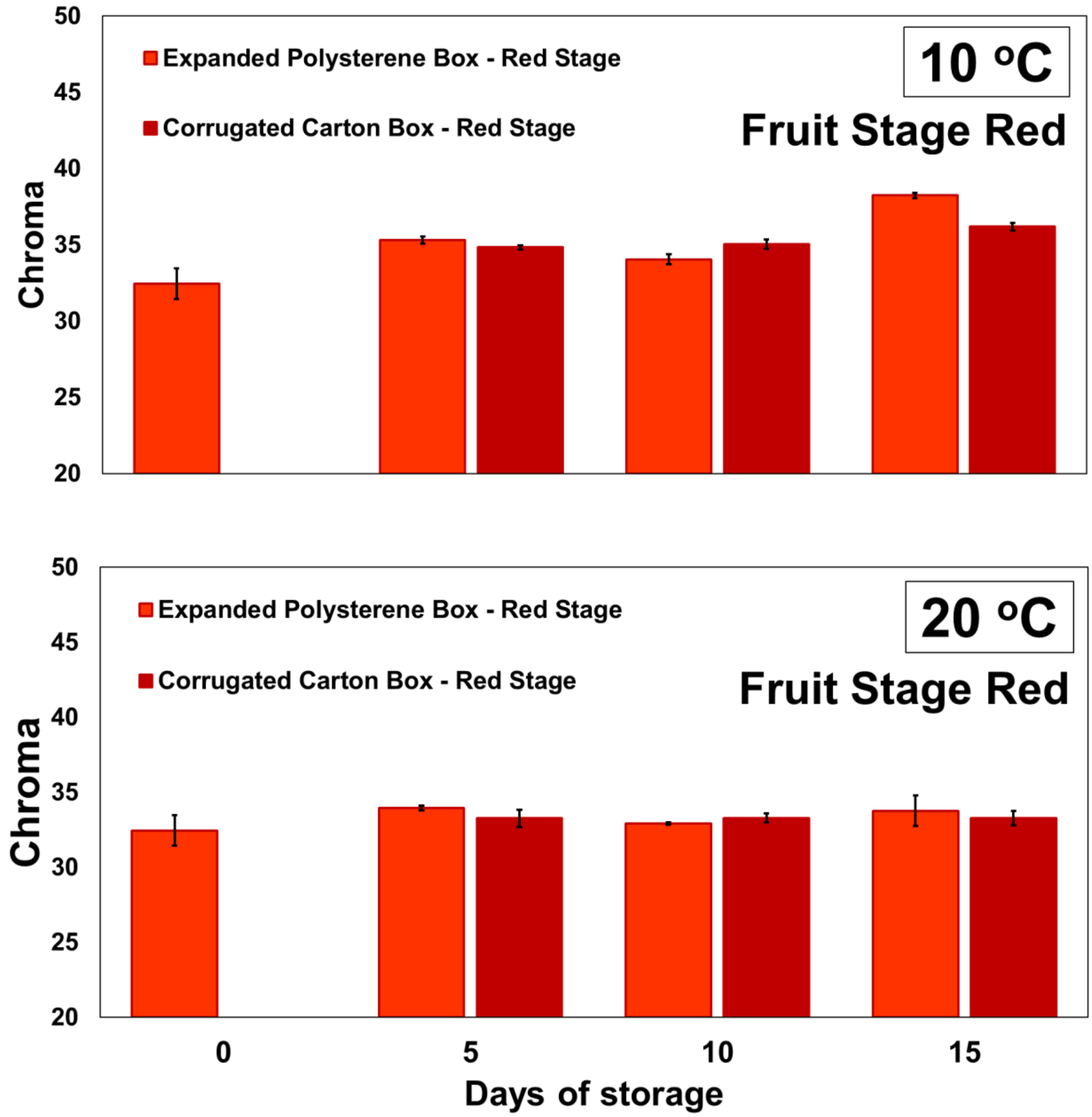


Figure 28. Chroma (± S.E.) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20^{o}C for 5, 10 and 15 days.

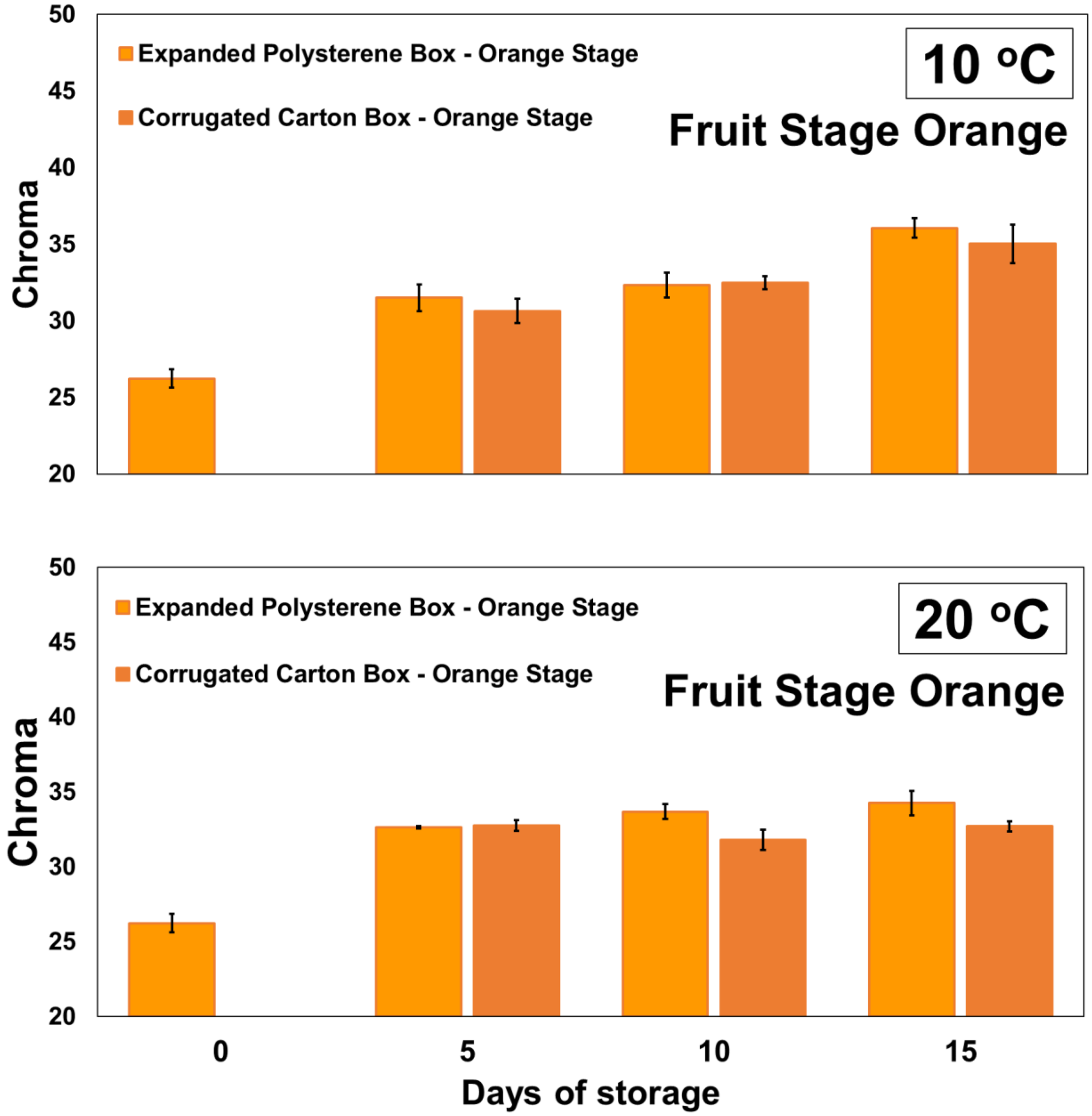


Figure 29. Chroma (± S.E.) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

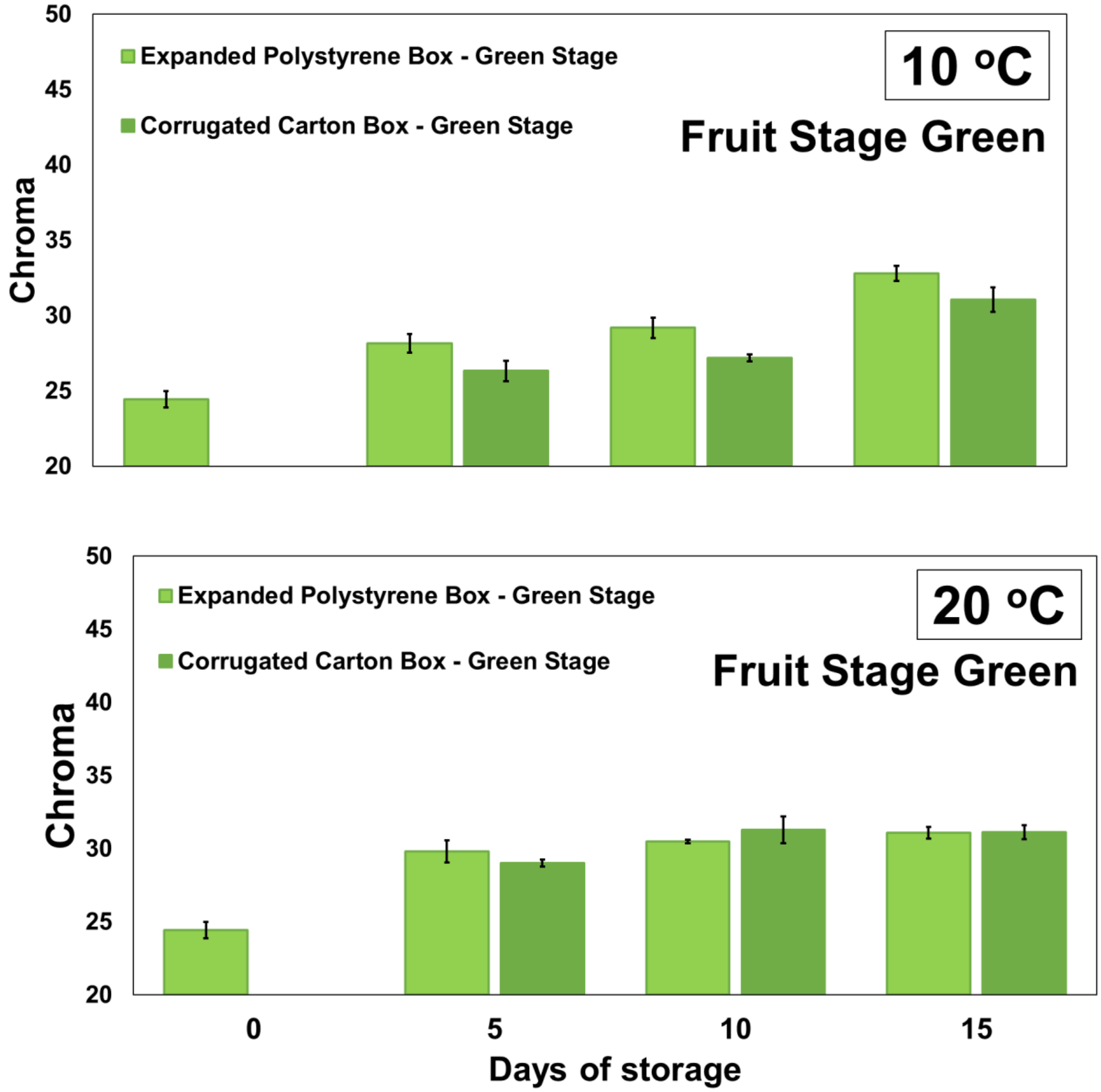


Figure 30. Chroma (± S.E.) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

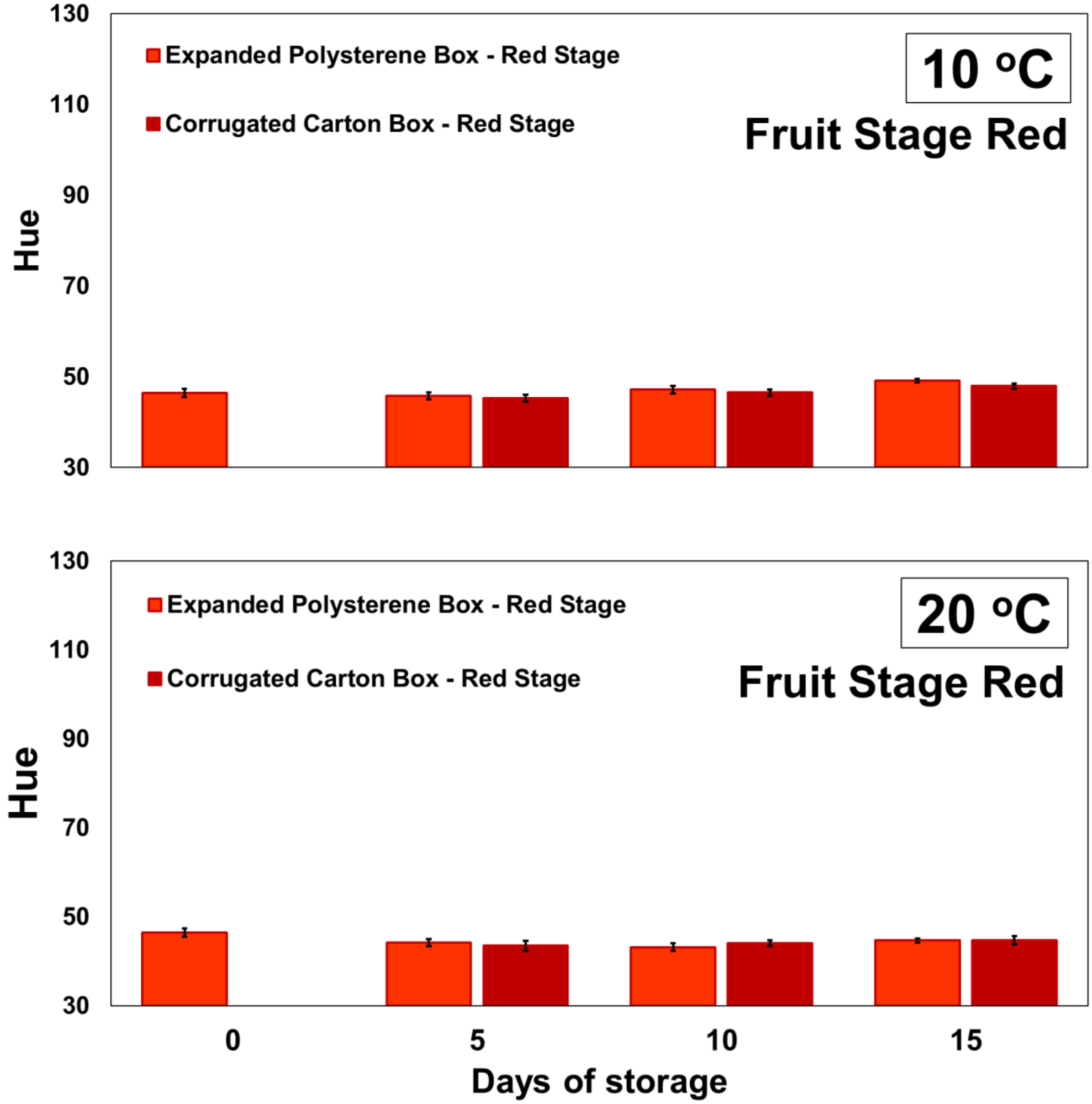


Figure 31. Hue angle (± S.E.) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 5, 10 and 15 days.

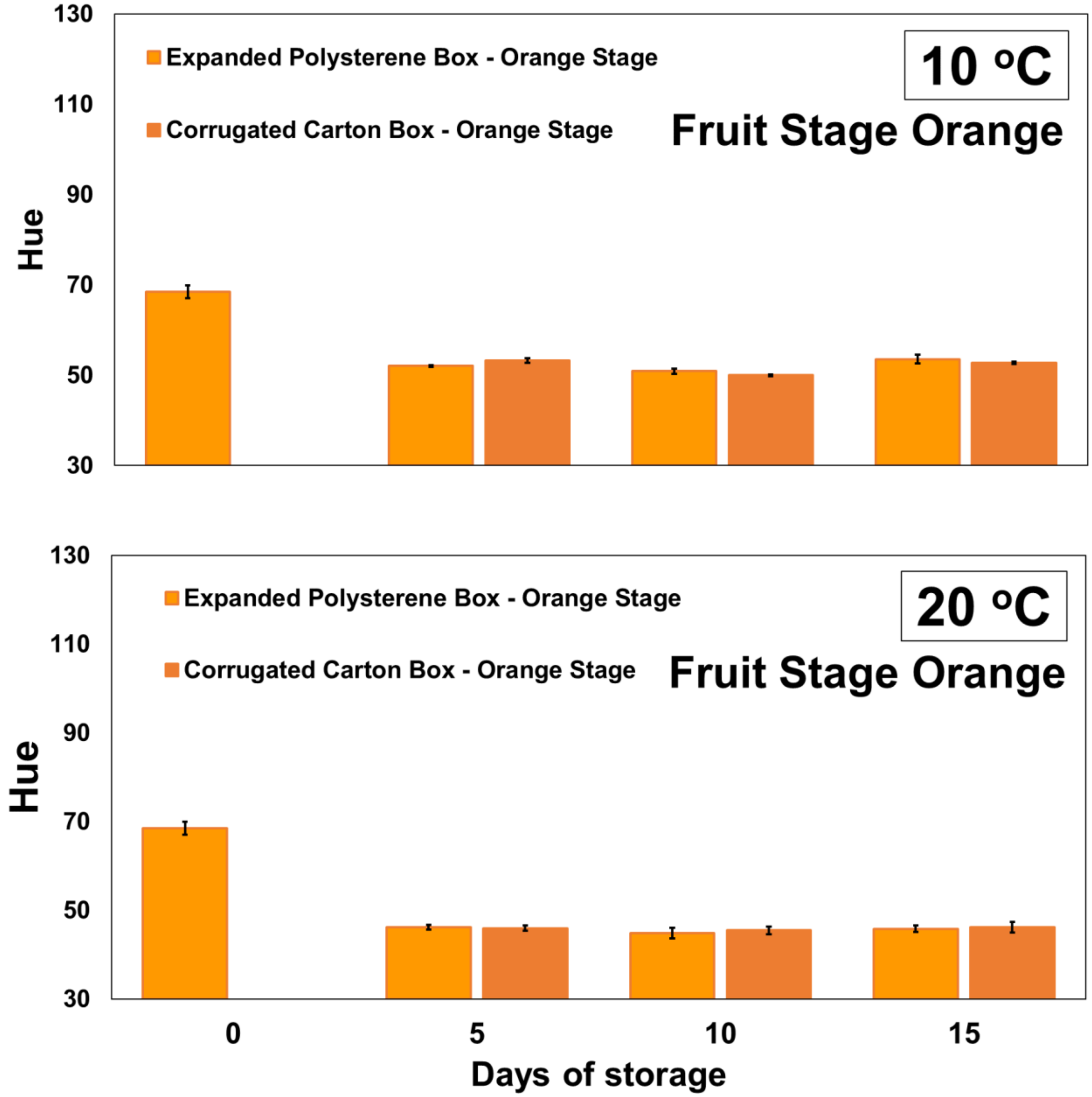


Figure 32. Hue angle (± S.E.) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 5, 10 and 15 days.

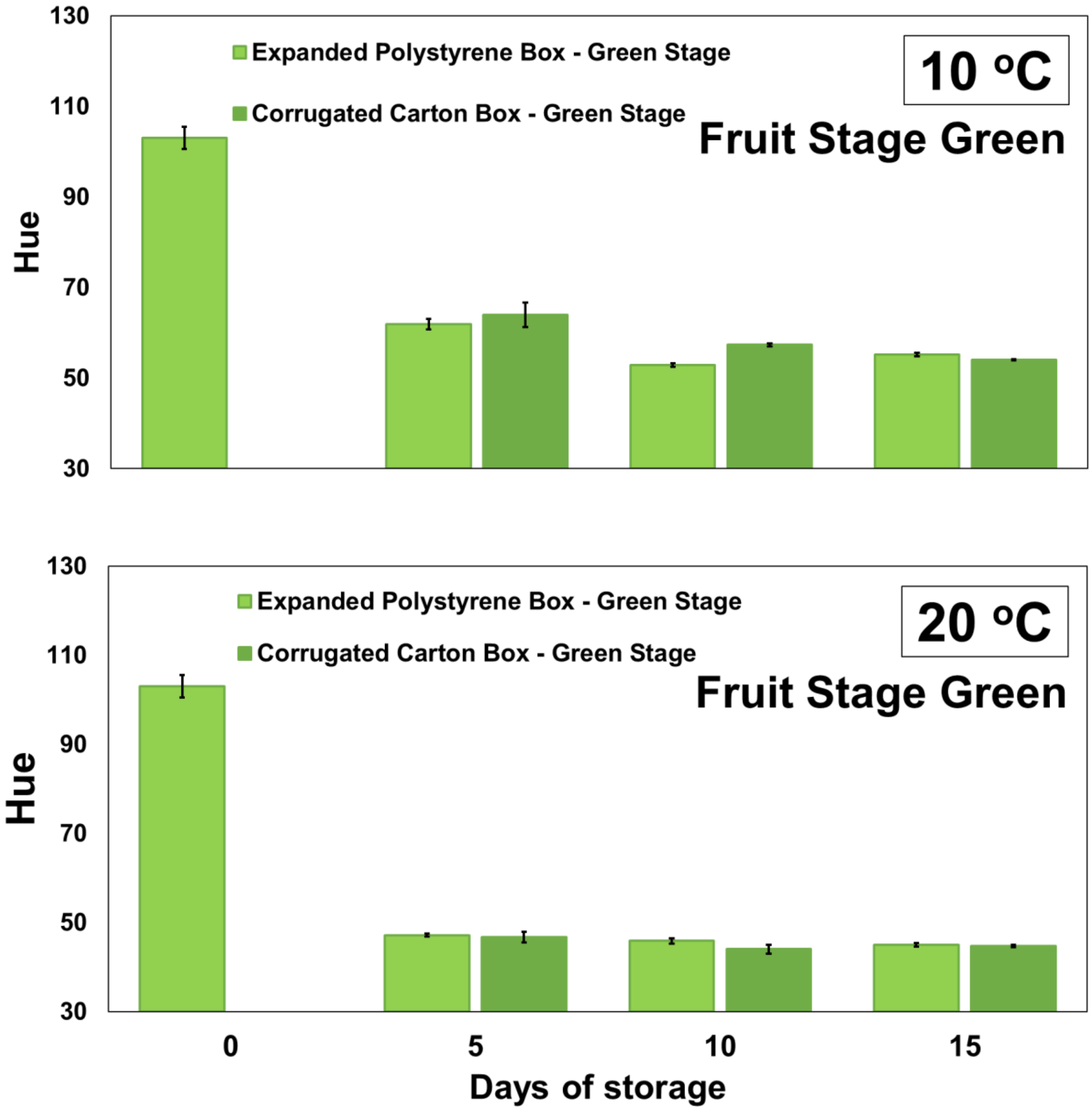


Figure 33. Hue angle (± S.E.) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 5, 10 and 15 days.

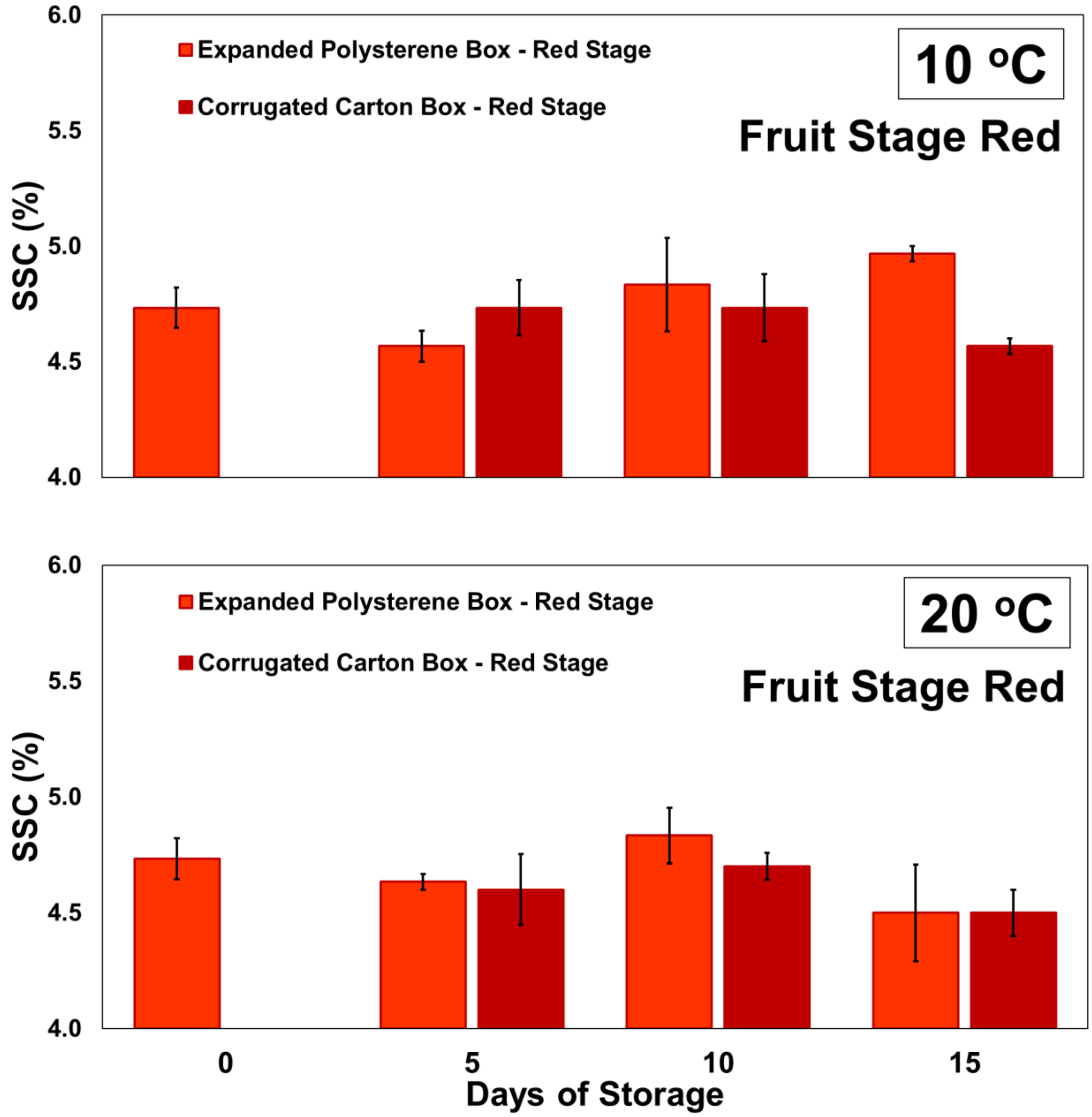


Figure 34. Soluble solids content (SSC) (%) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

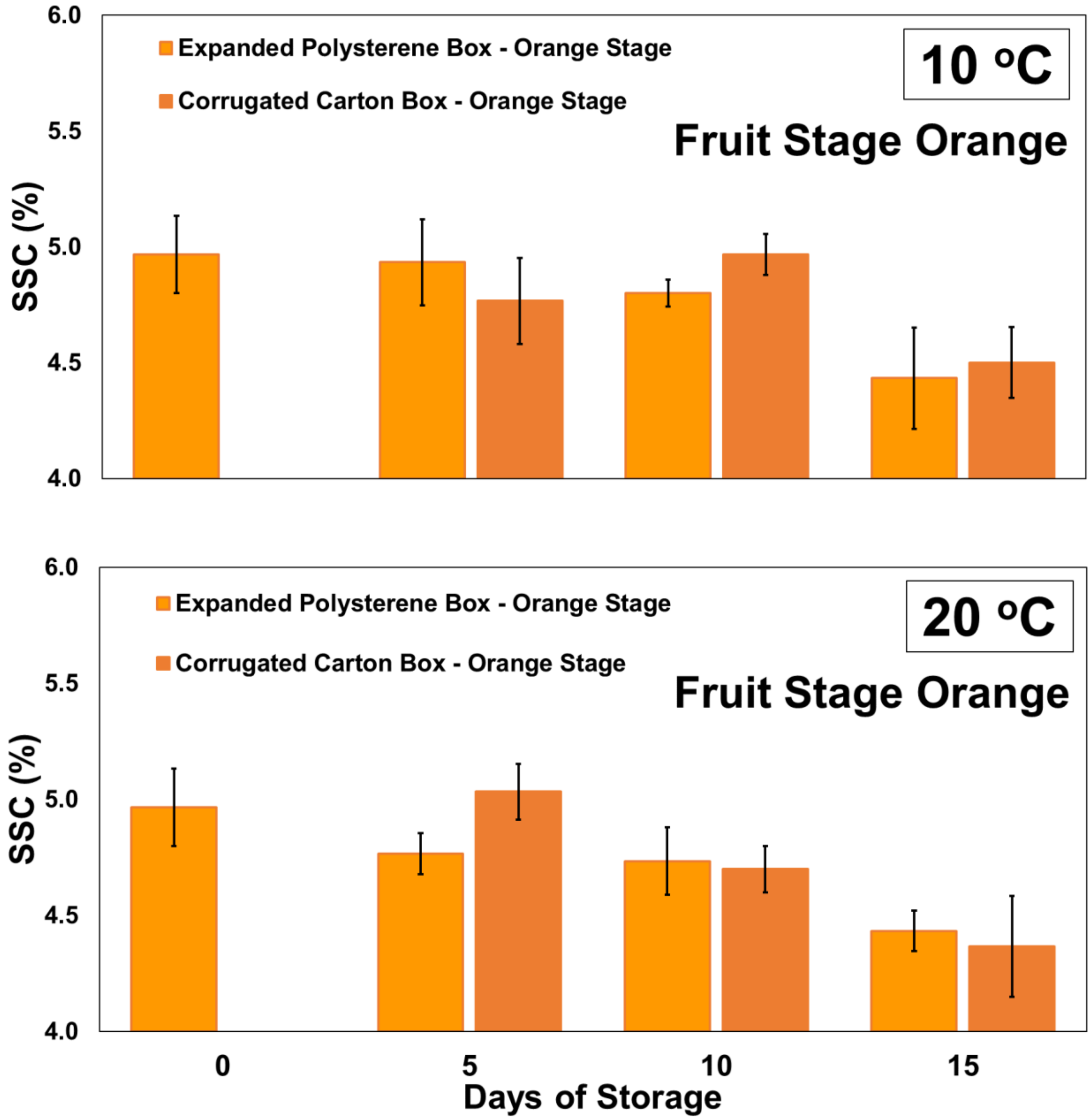


Figure 35. Soluble solids content (SSC) (%) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

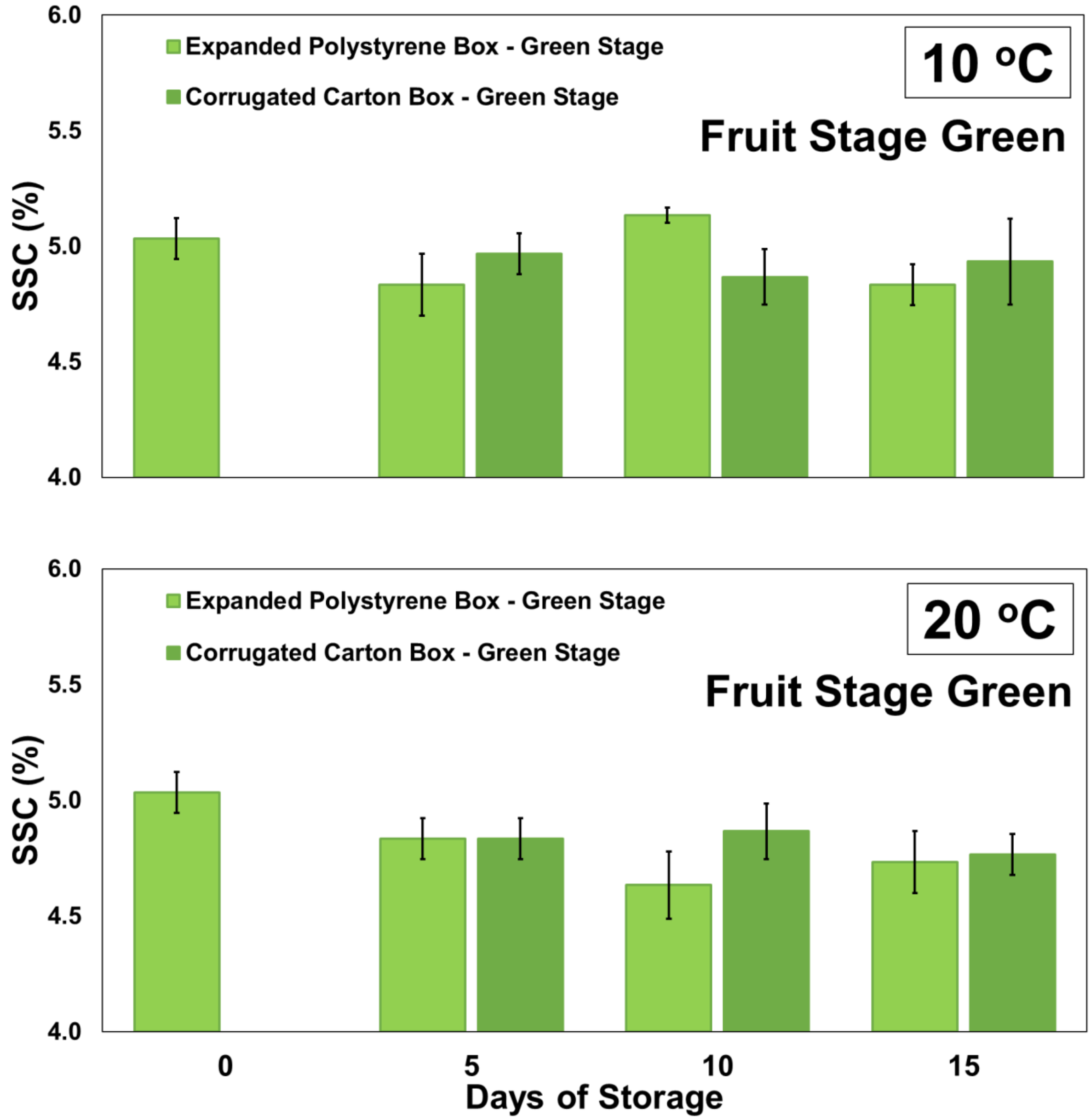


Figure 36. Soluble solids content (SSC) (%) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 5, 10 and 15 days.

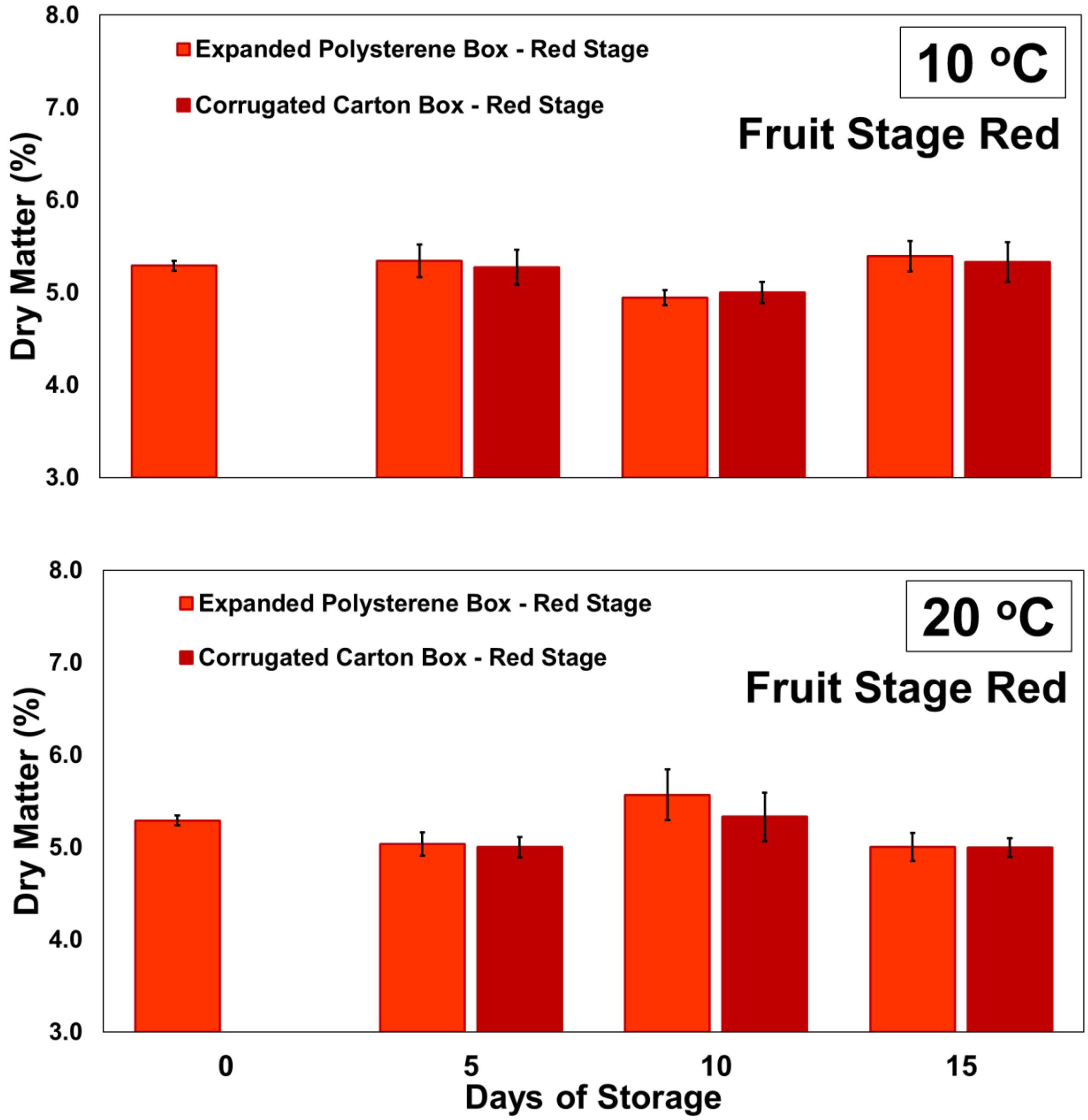


Figure 37. Dry matter content (%) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

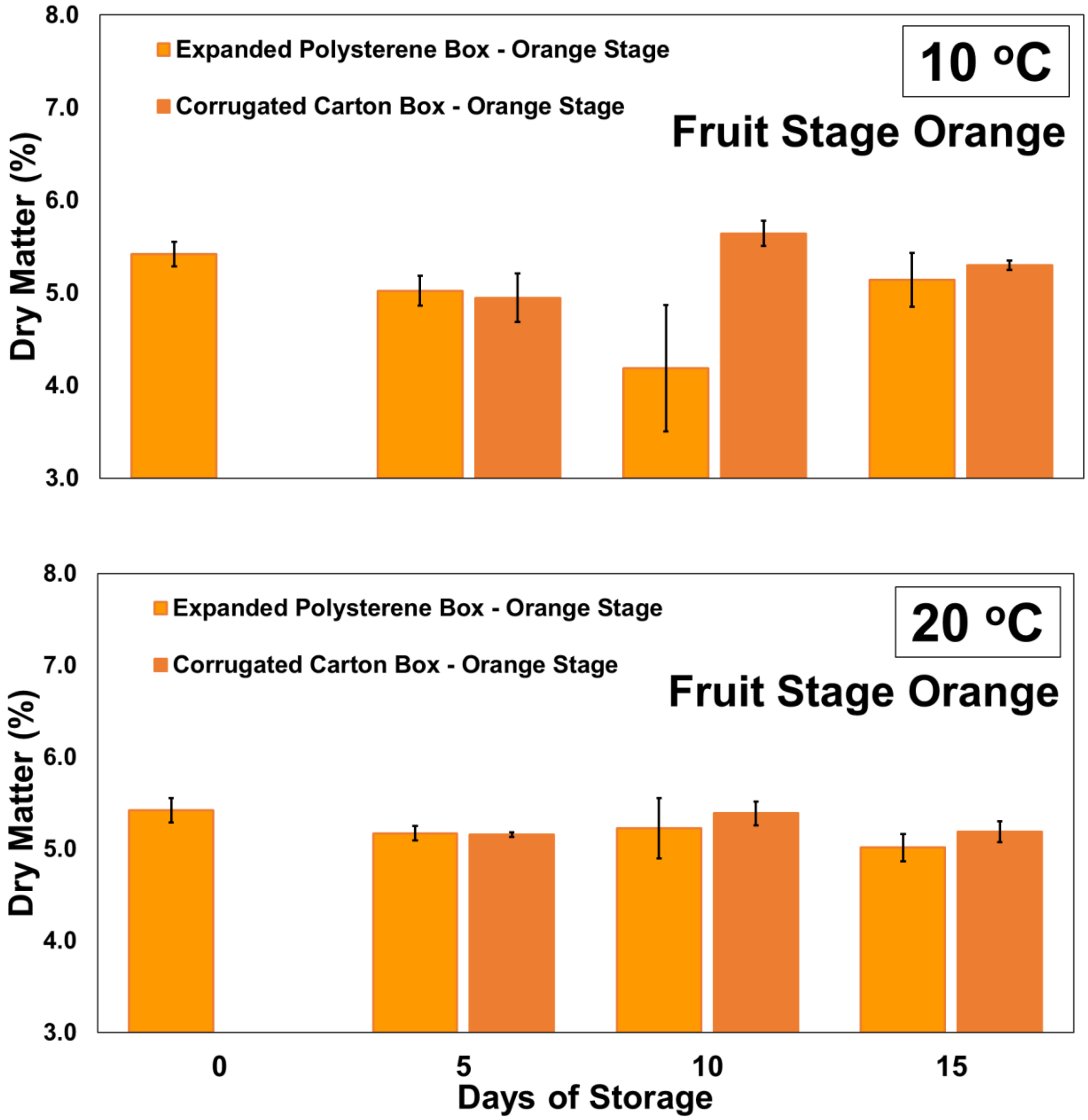


Figure 38. Dry matter content (%) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 5, 10 and 15 days.

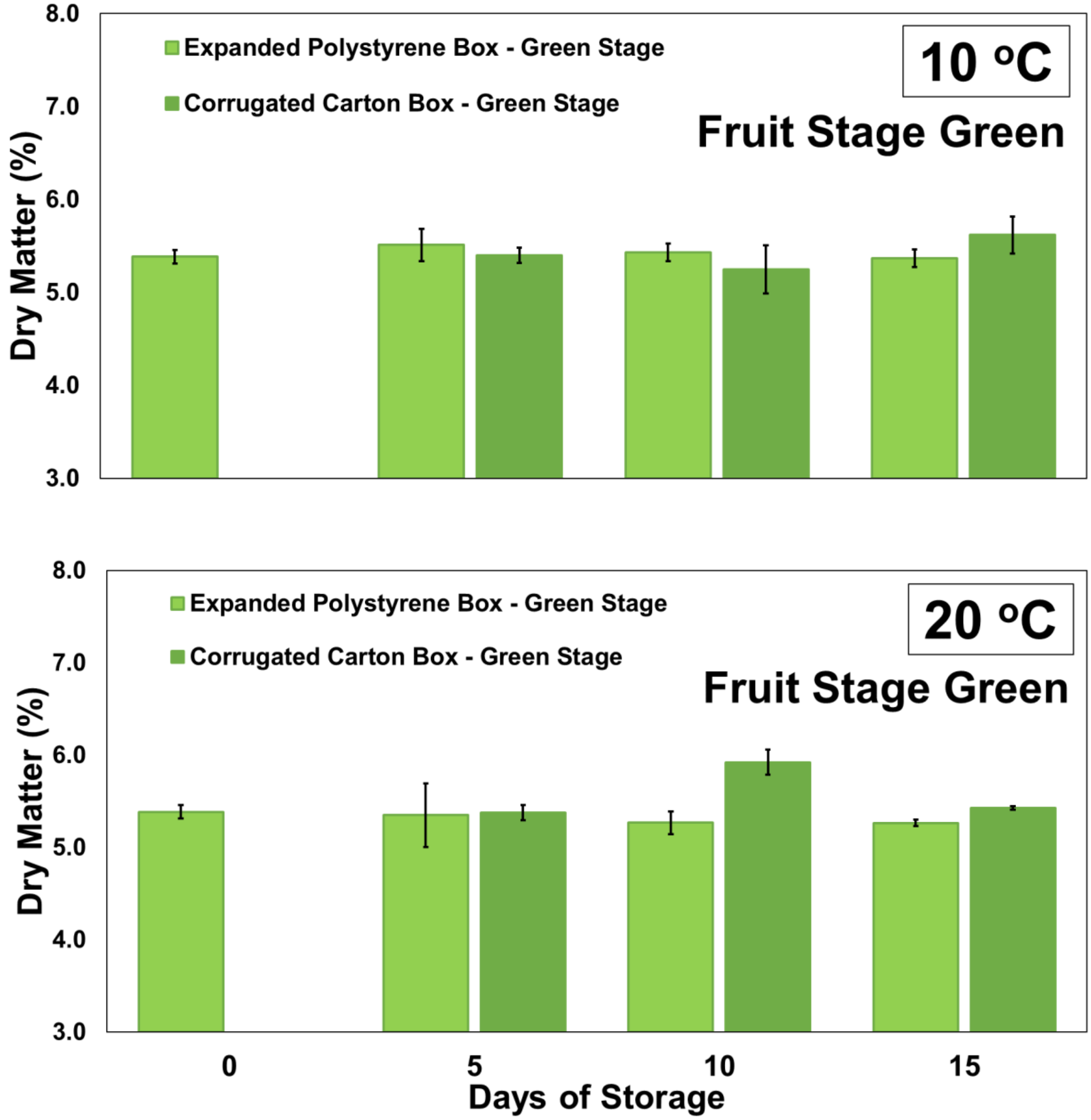


Figure 39. Dry matter content (%) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 5, 10 and 15 days.

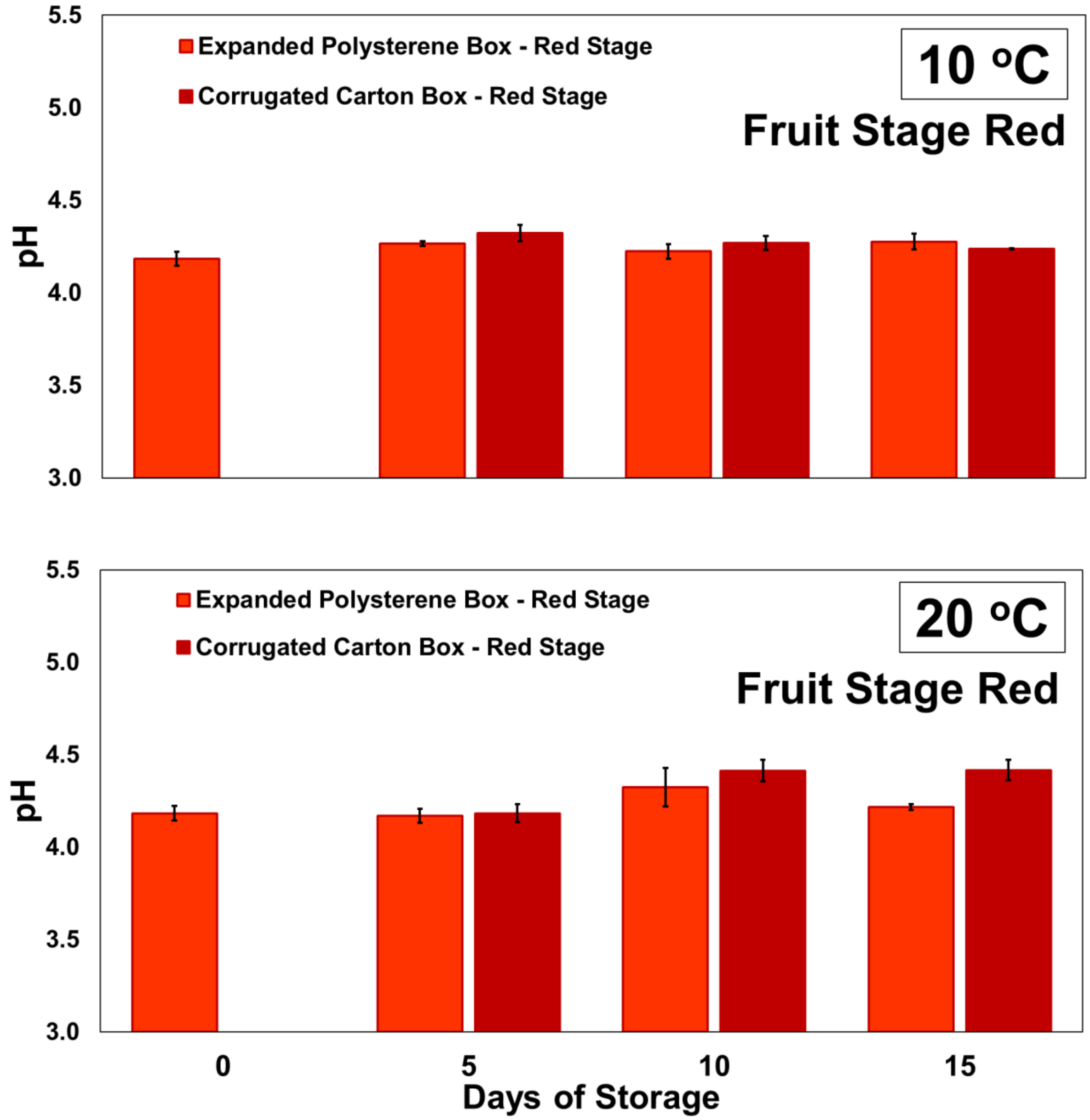


Figure 40. pH of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

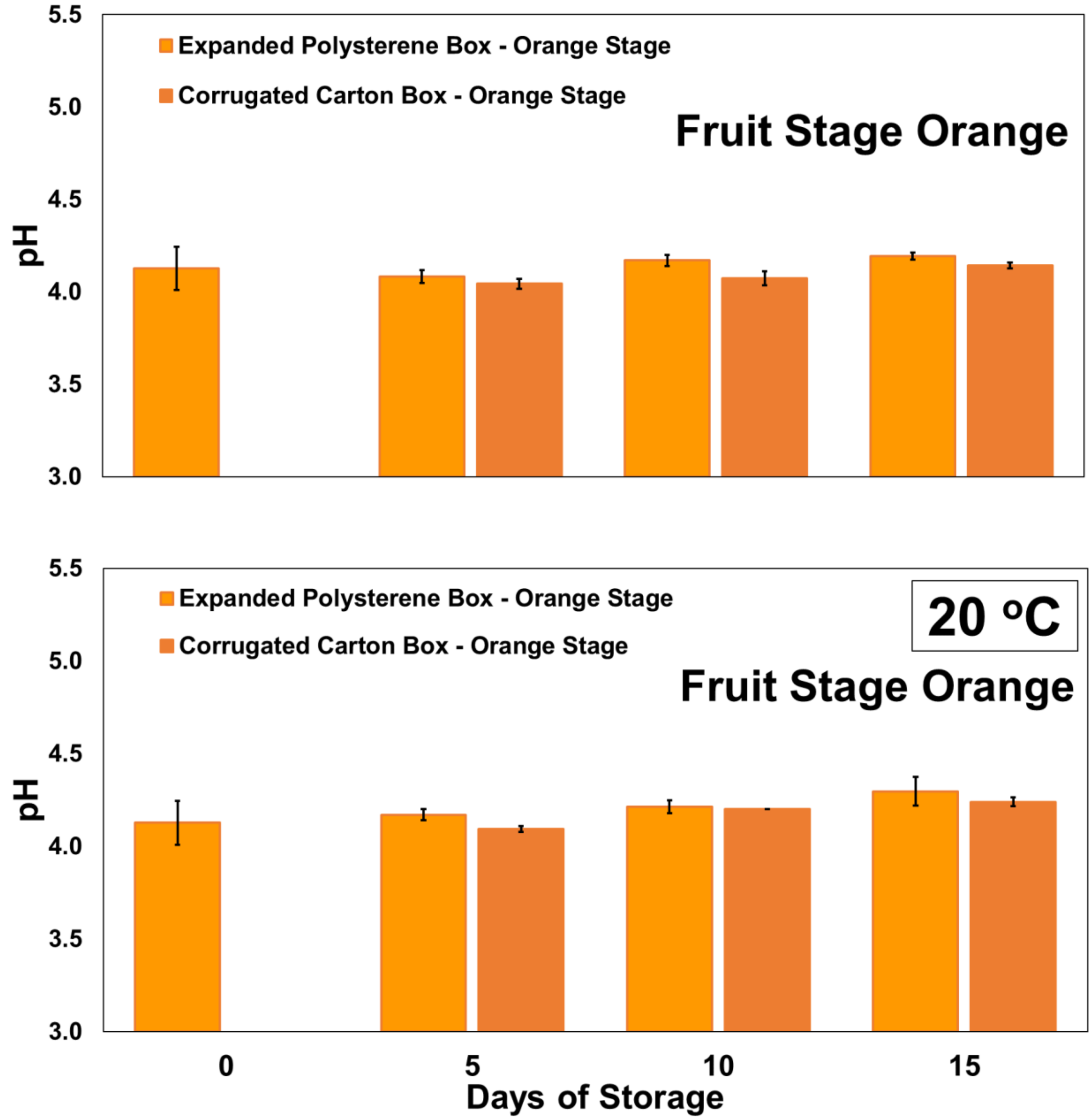


Figure 41. pH of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

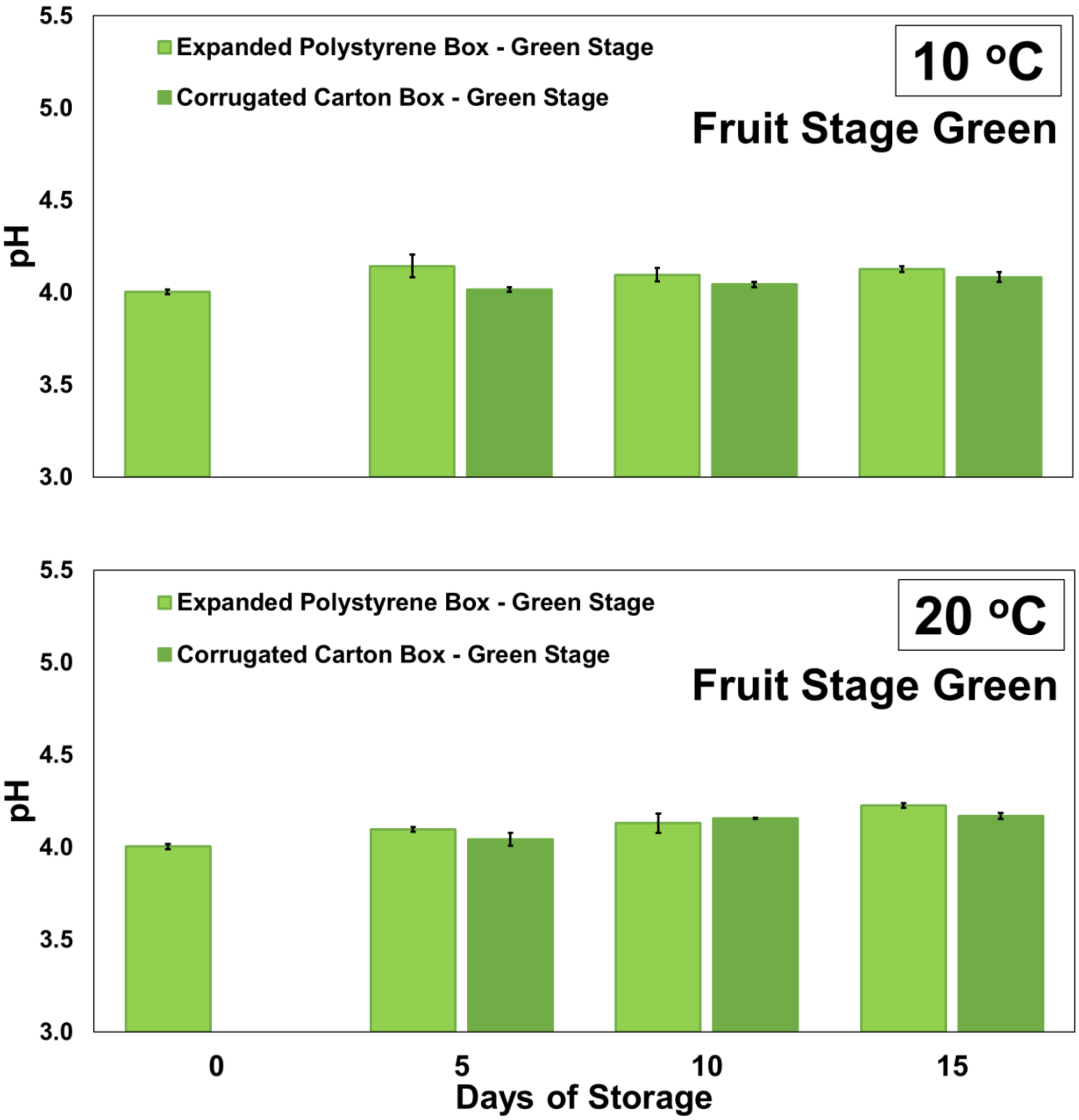


Figure 42. pH of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 5, 10 and 15 days.

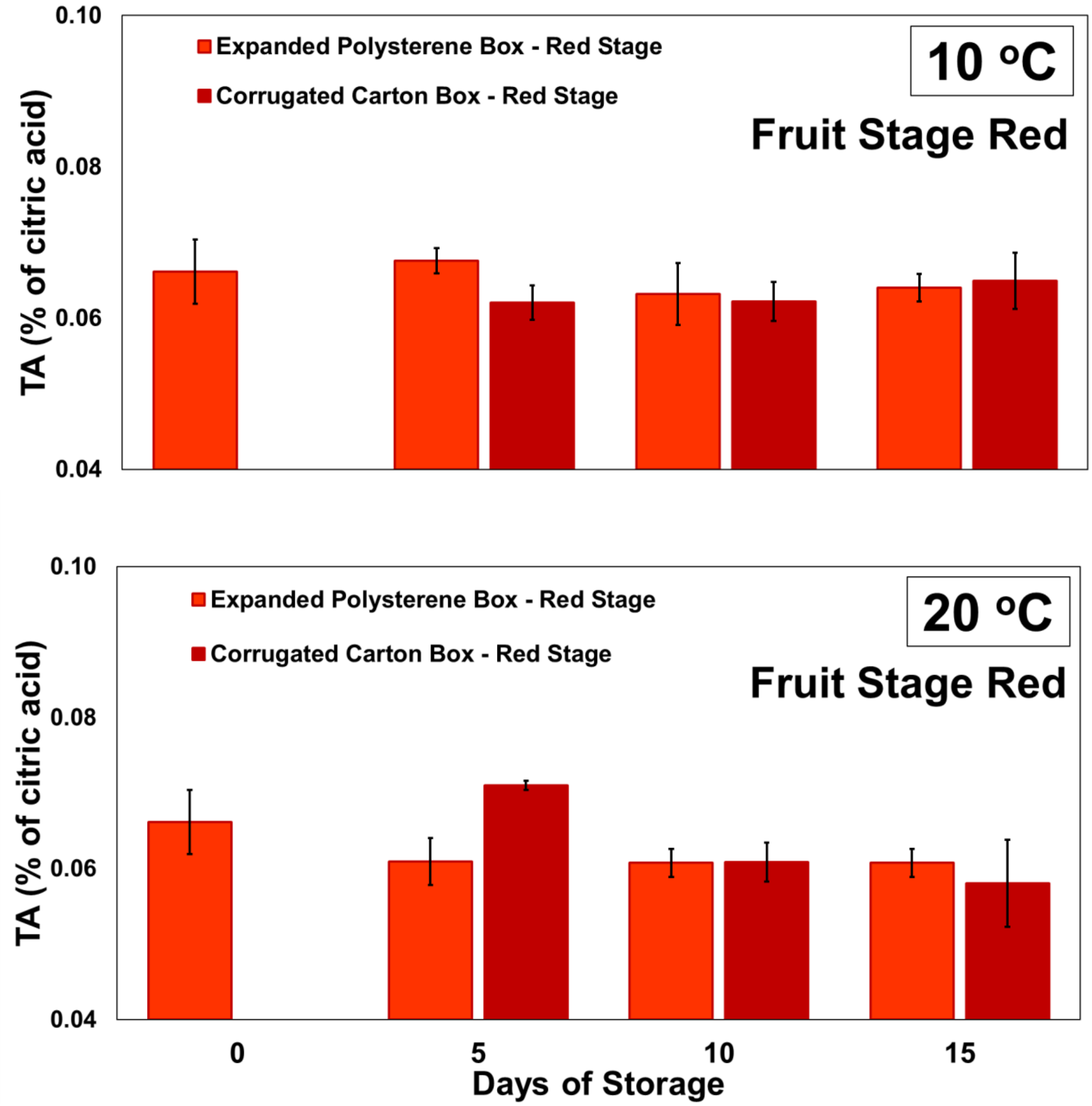


Figure 43. Titratable acidity (TA) (% citric acid) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

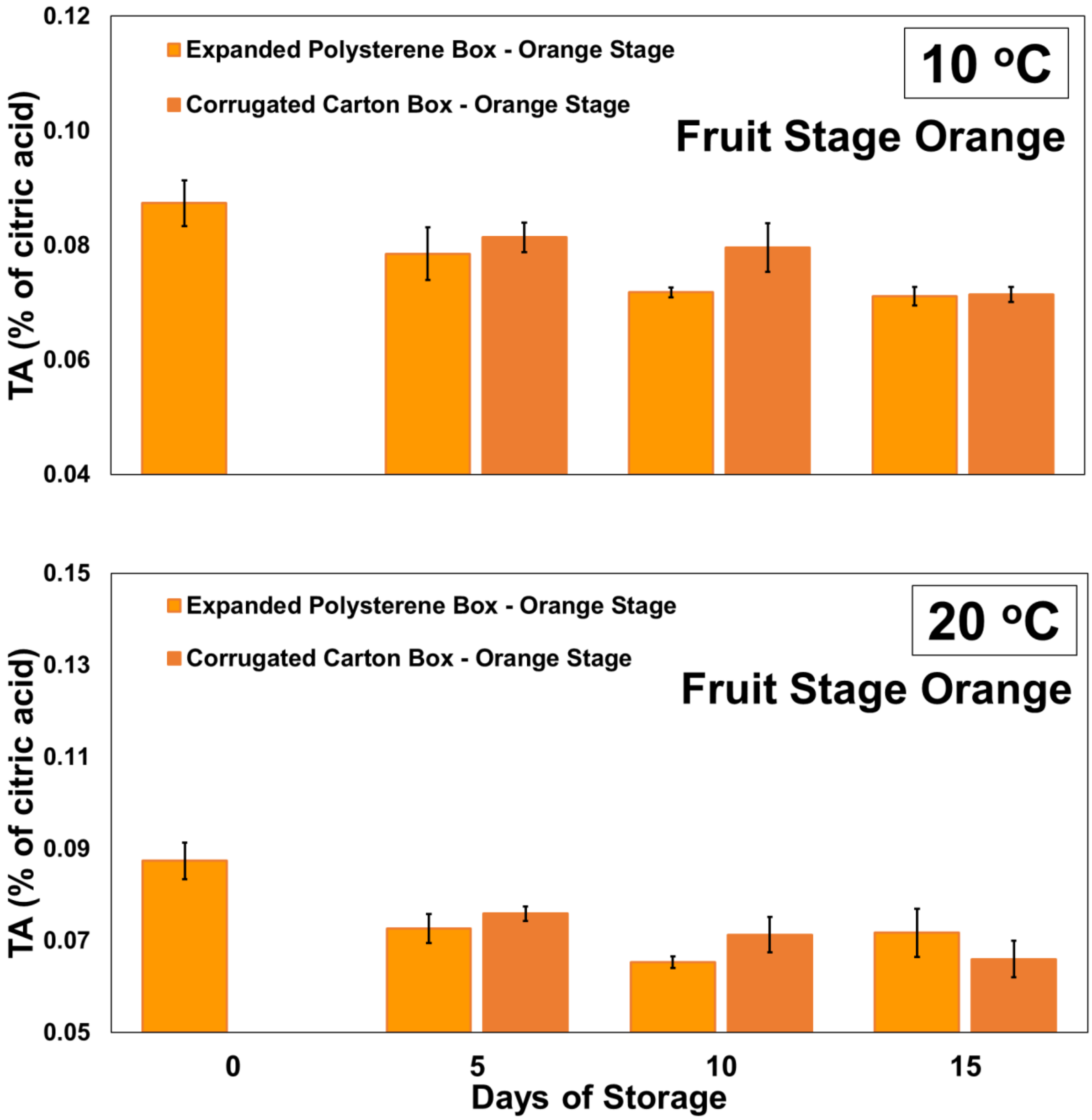


Figure 44. Titratable acidity (TA) (% citric acid) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 5, 10 and 15 days.

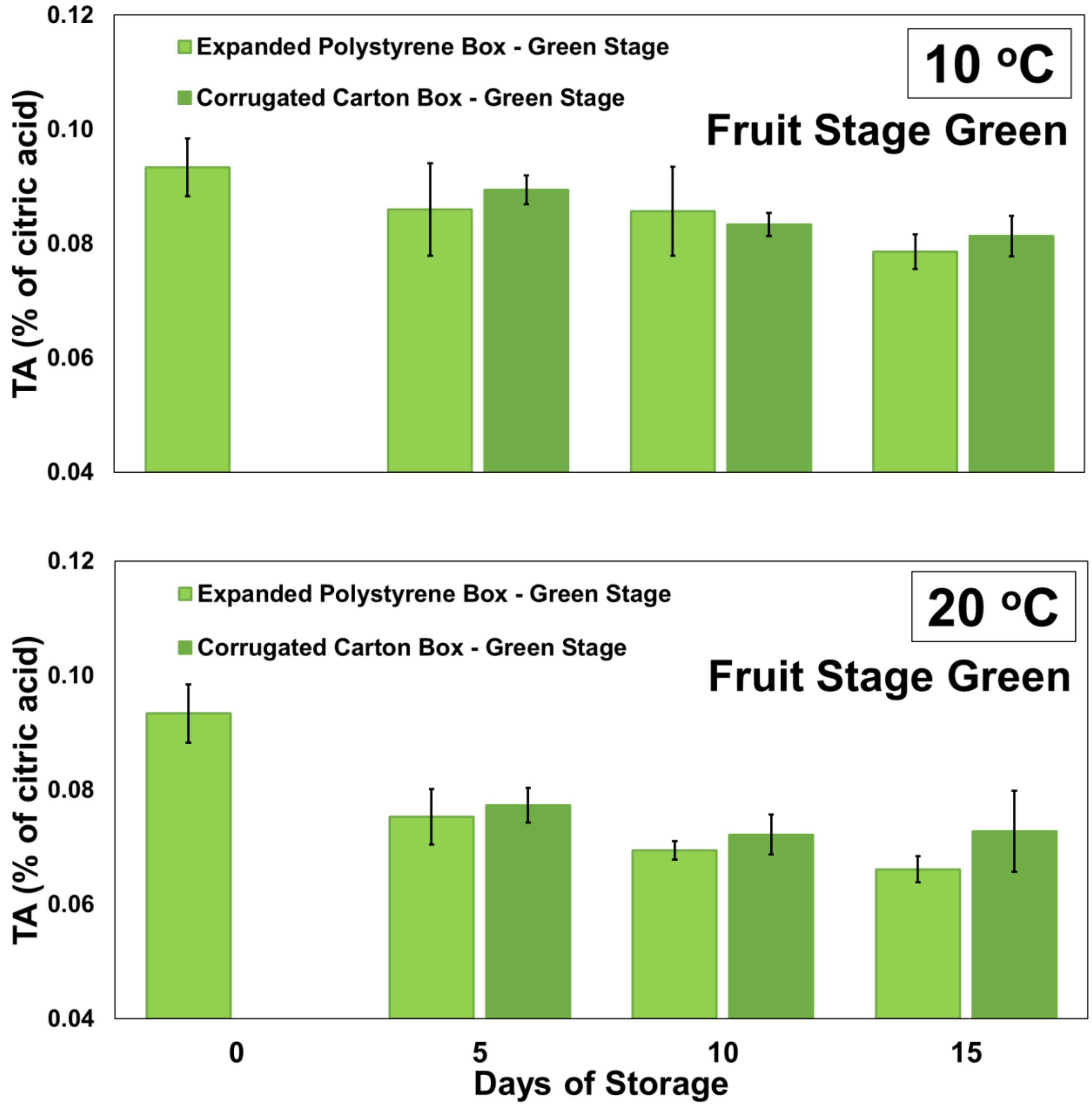


Figure 45. Titratable acidity (TA) (% citric acid) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 5, 10 and 15 days.

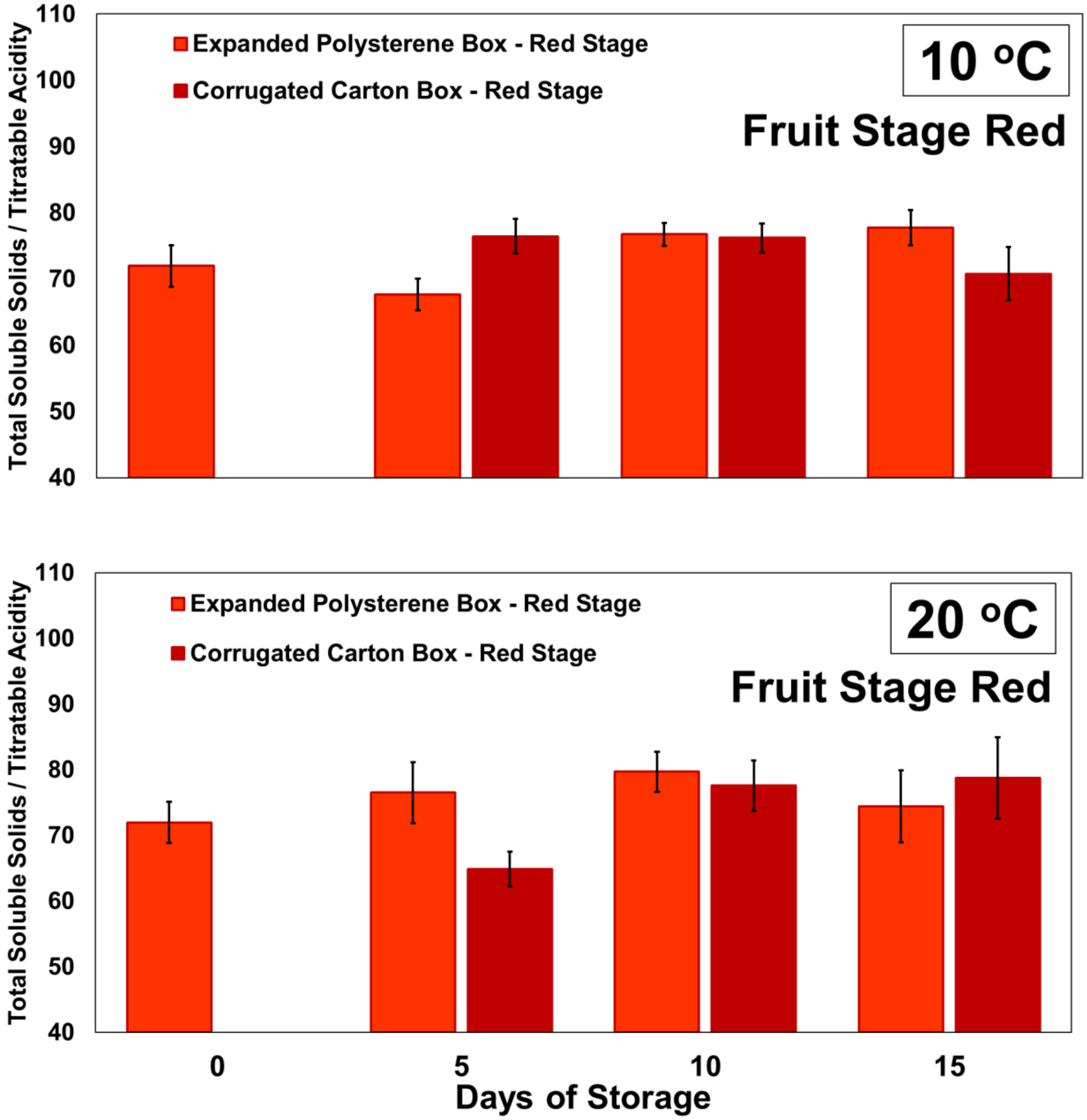


Figure 46. Total soluble solids content/ titratable acidity ratio of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

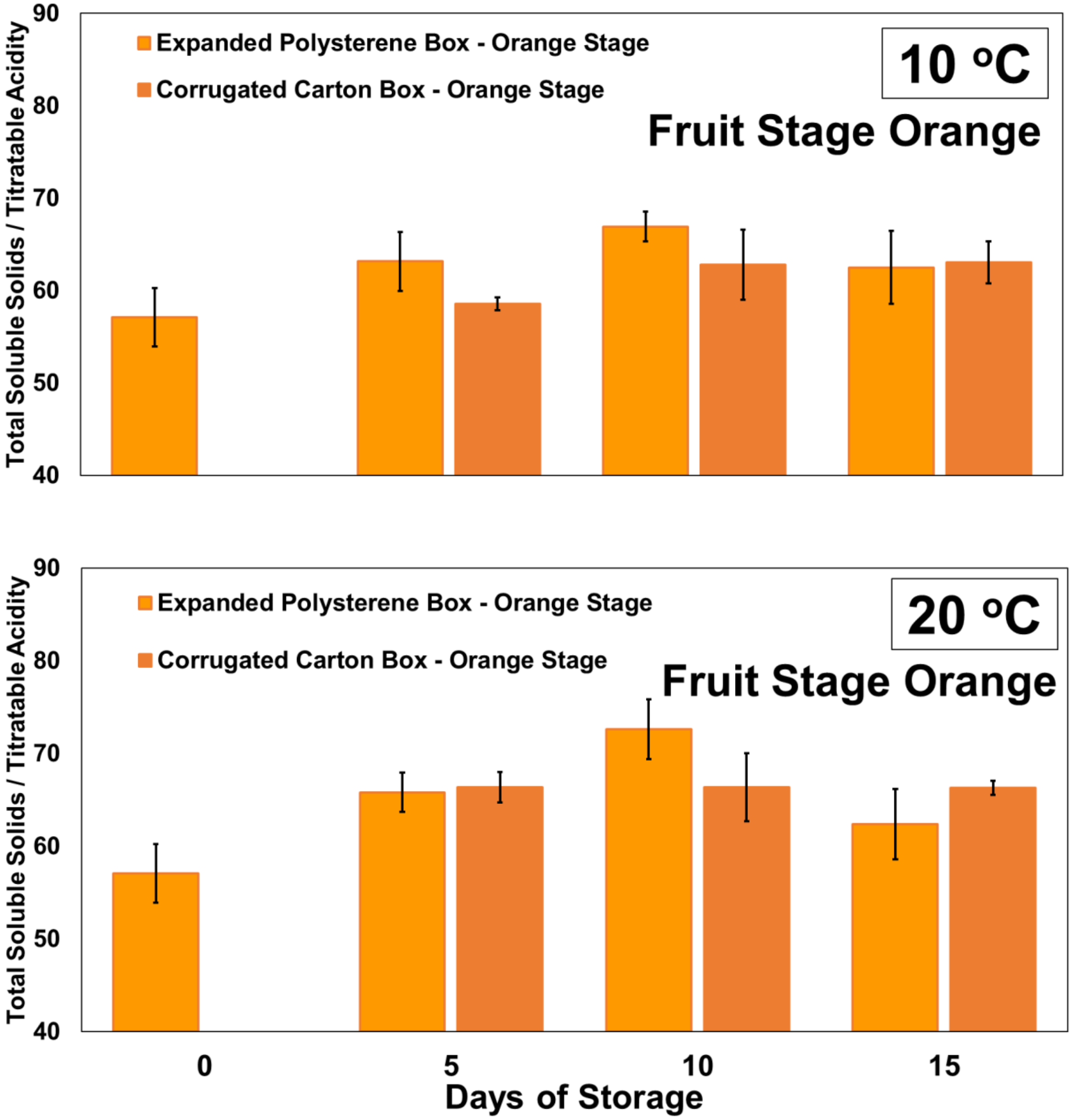


Figure 47. Total soluble solids content/ titratable acidity ratio of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 5, 10 and 15 days.

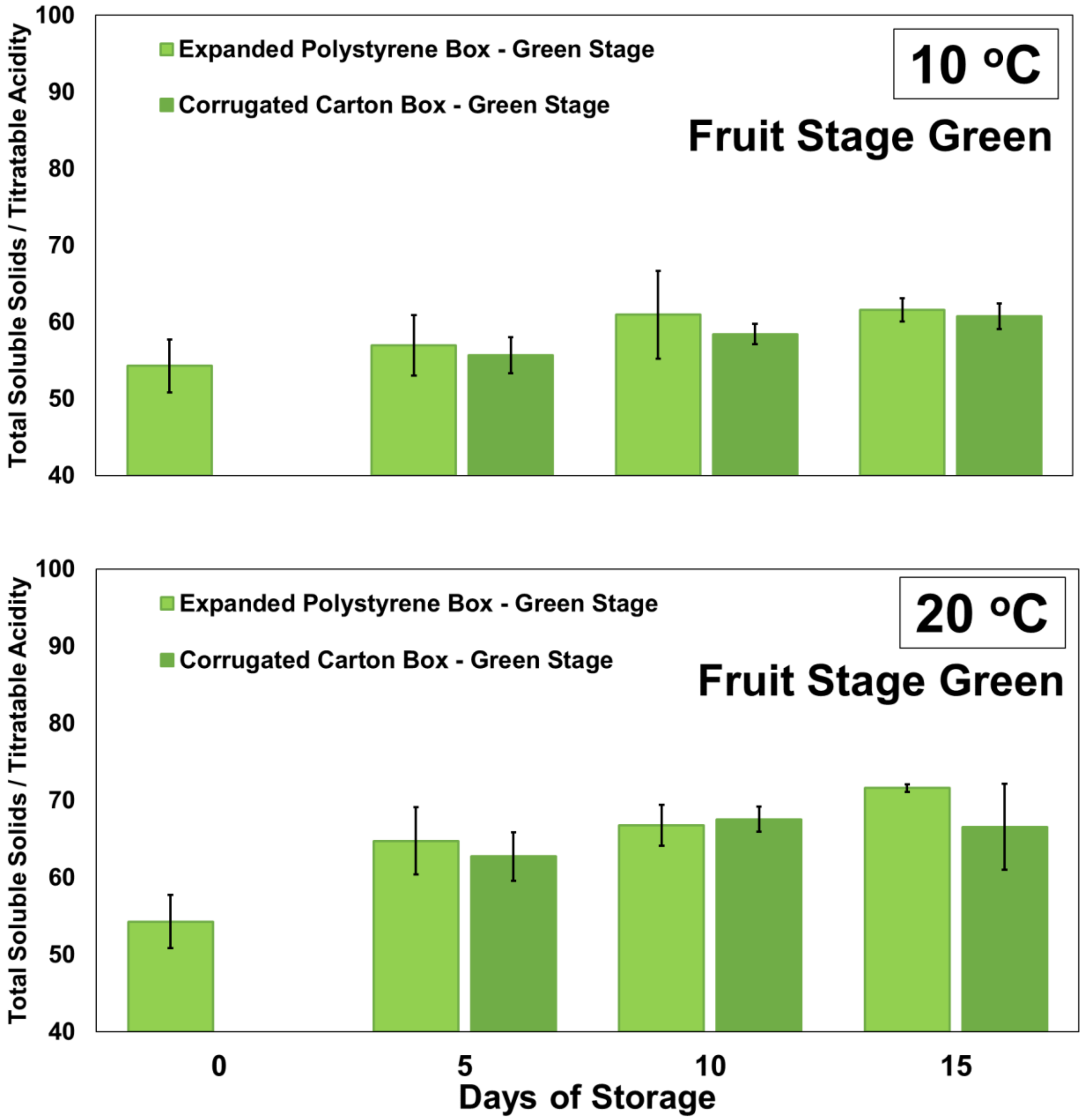


Figure 48. Total soluble solids content/ titratable acidity ratio of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

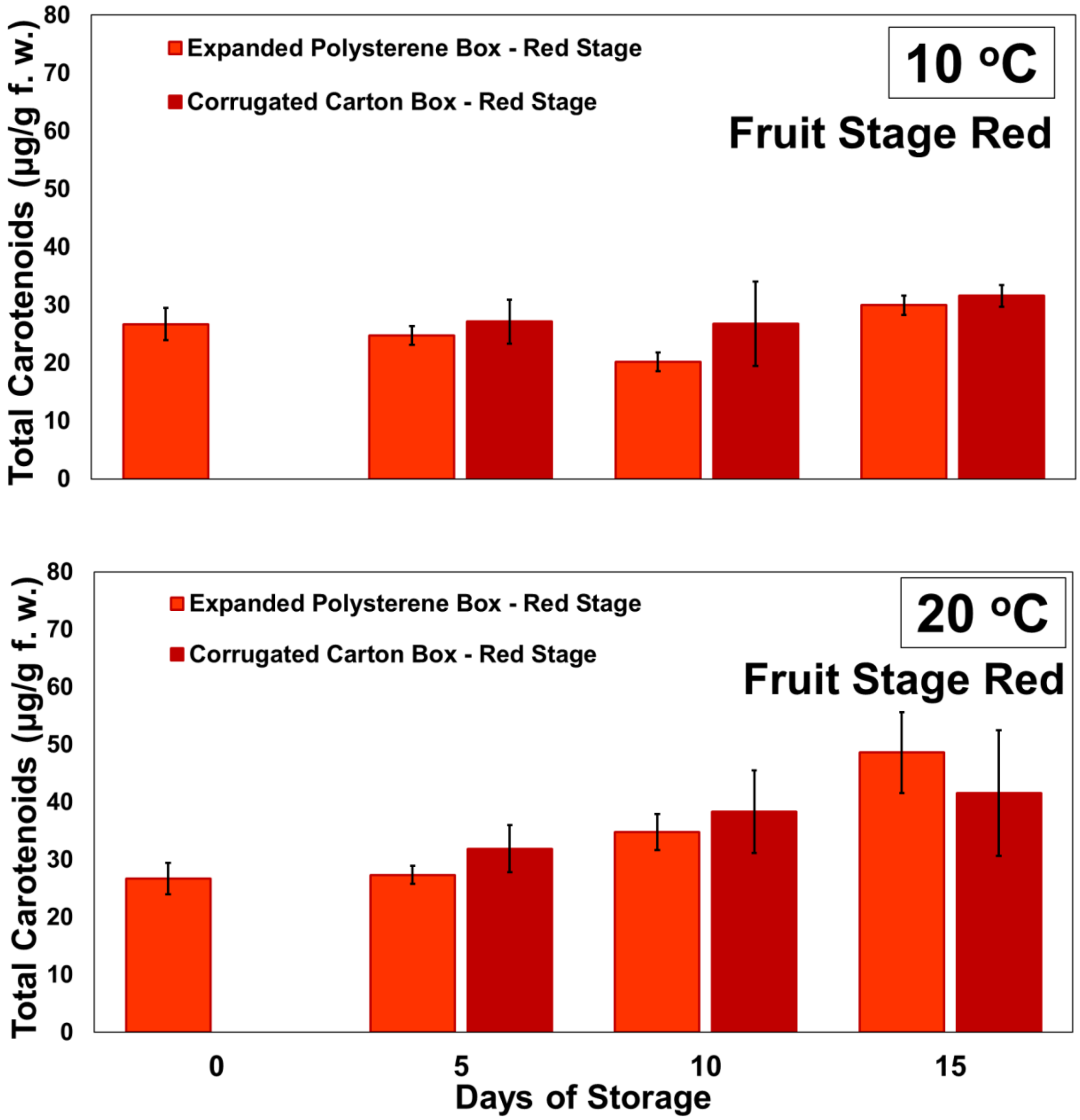


Figure 49. Total carotenoid content (µg/g f.w.) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20^{o}C for 5, 10 and 15 days.

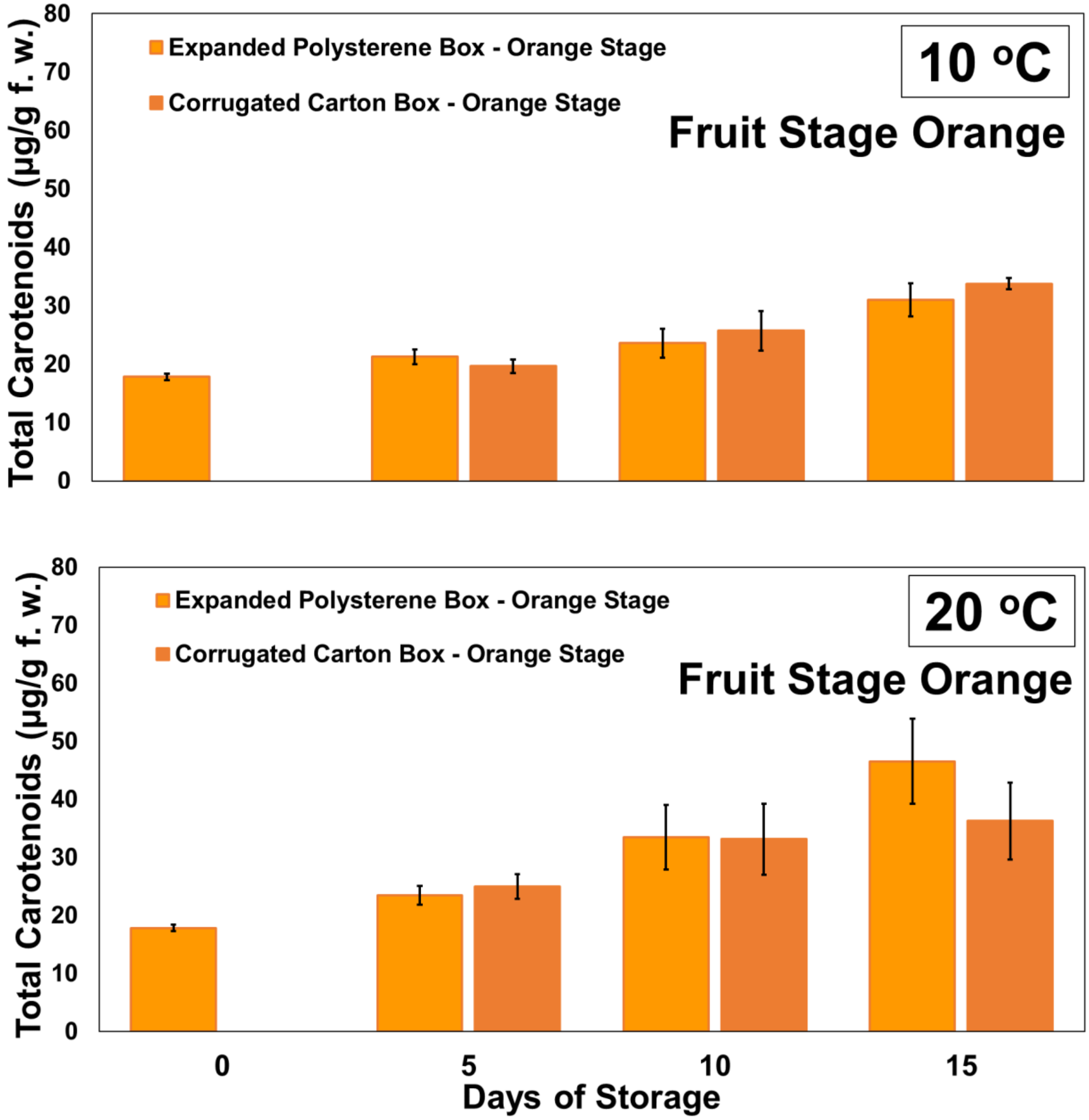


Figure 50. Total carotenoid content (µg/g f.w.) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 5, 10 and 15 days.

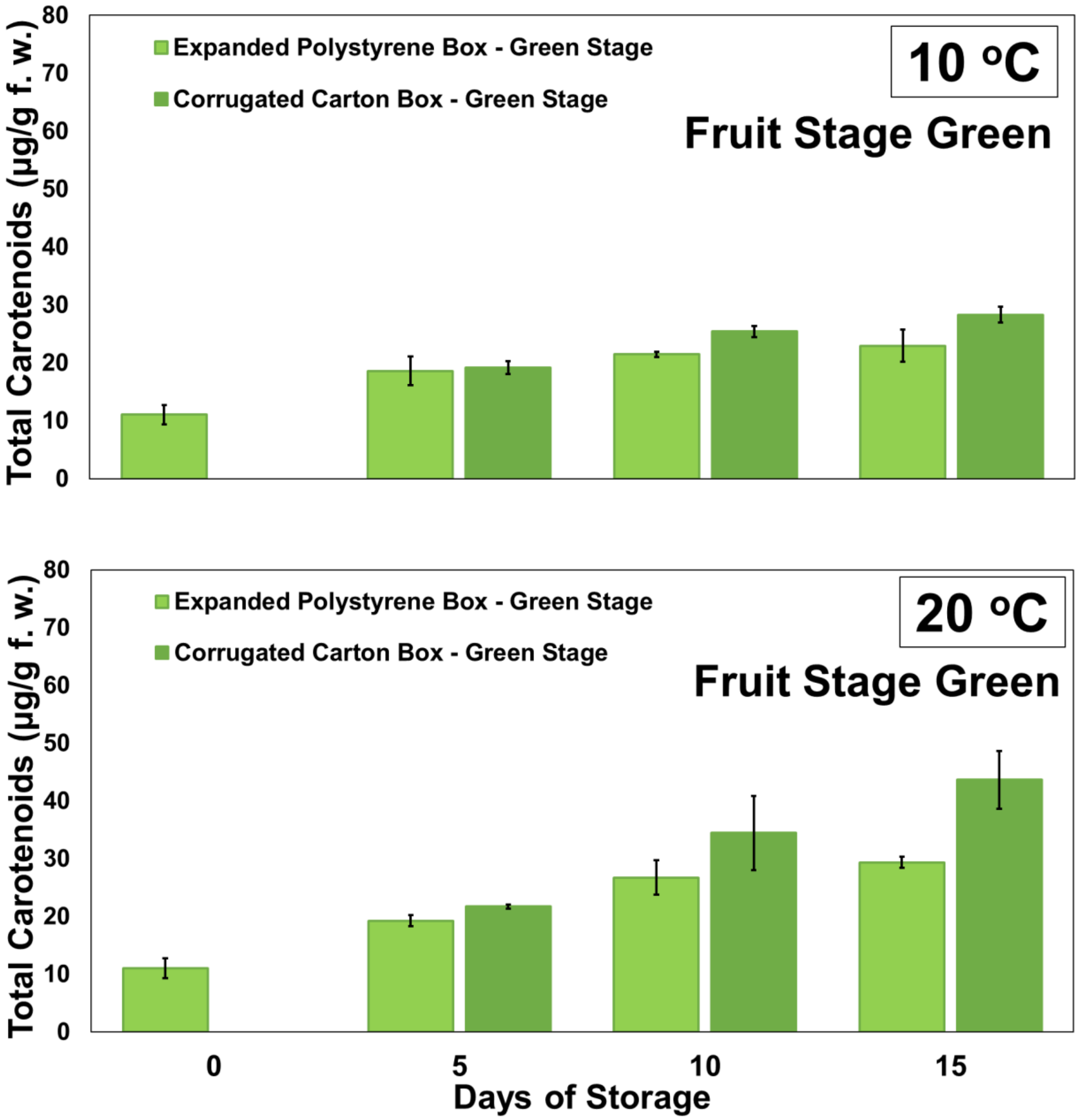


Figure 51. Total carotenoid content (µg/g f.w.) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

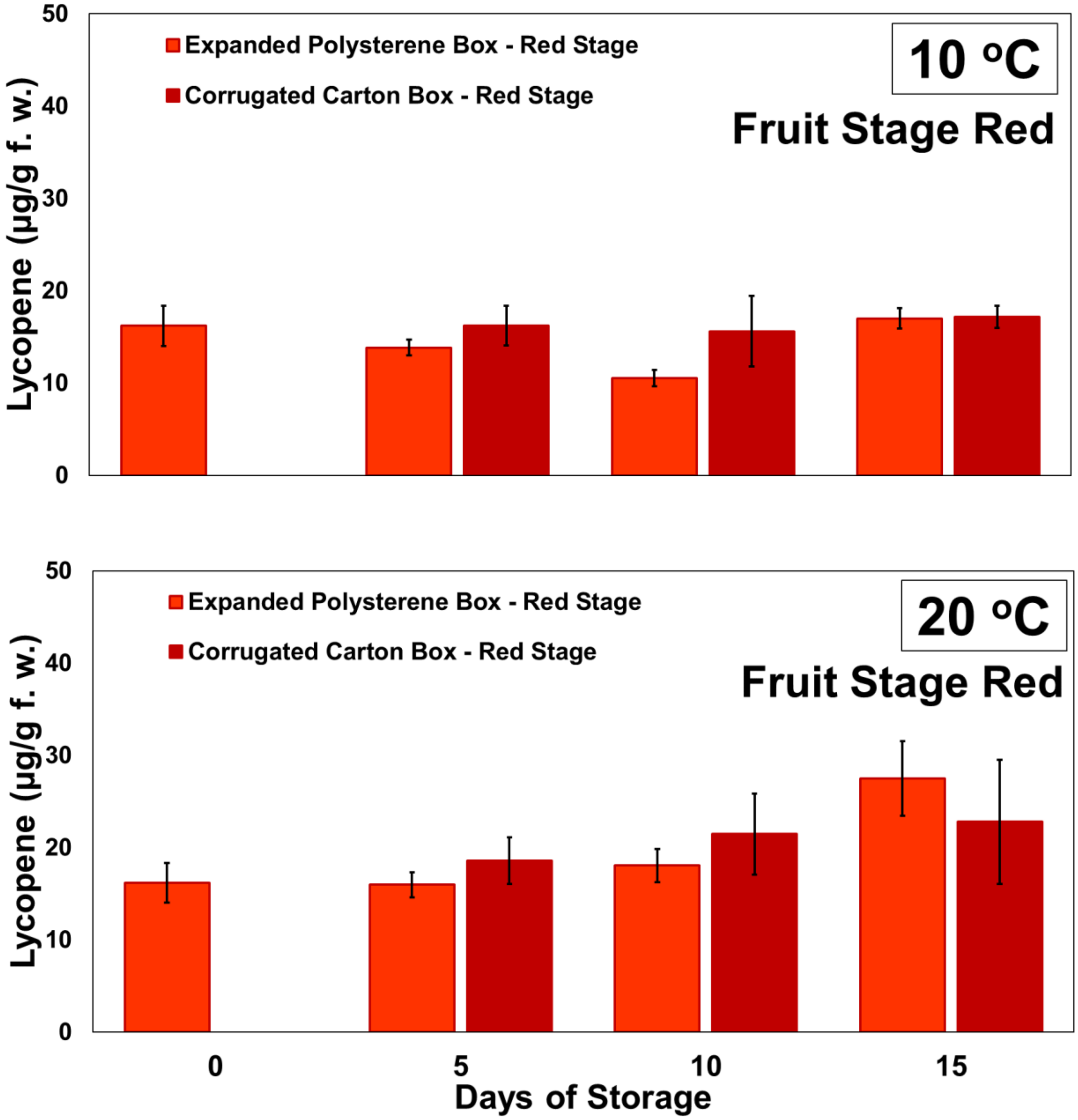


Figure 52. Lycopene content (µg/g f.w.) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

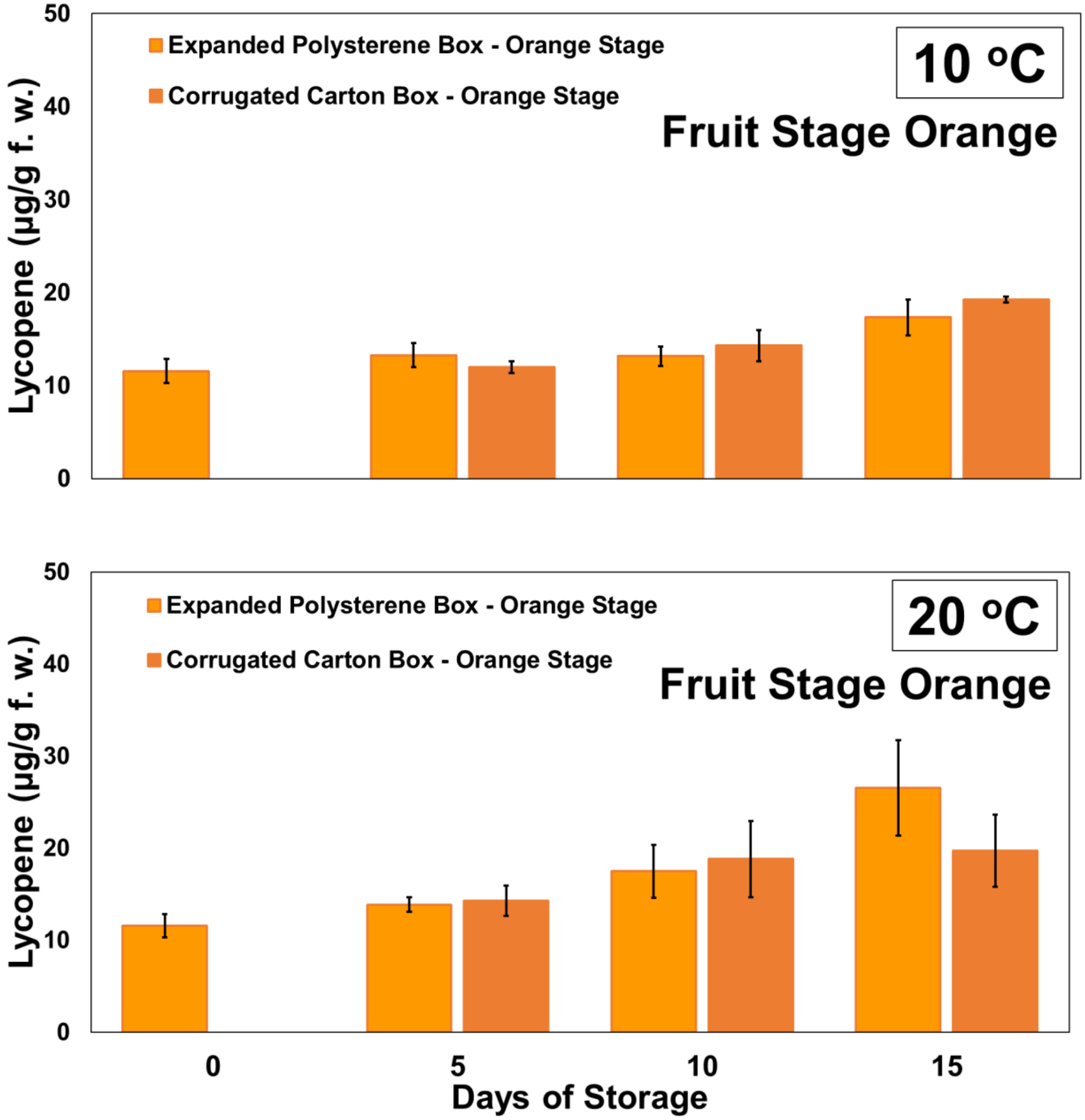


Figure 53. Lycopene content (µg/g f.w.) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 5, 10 and 15 days.

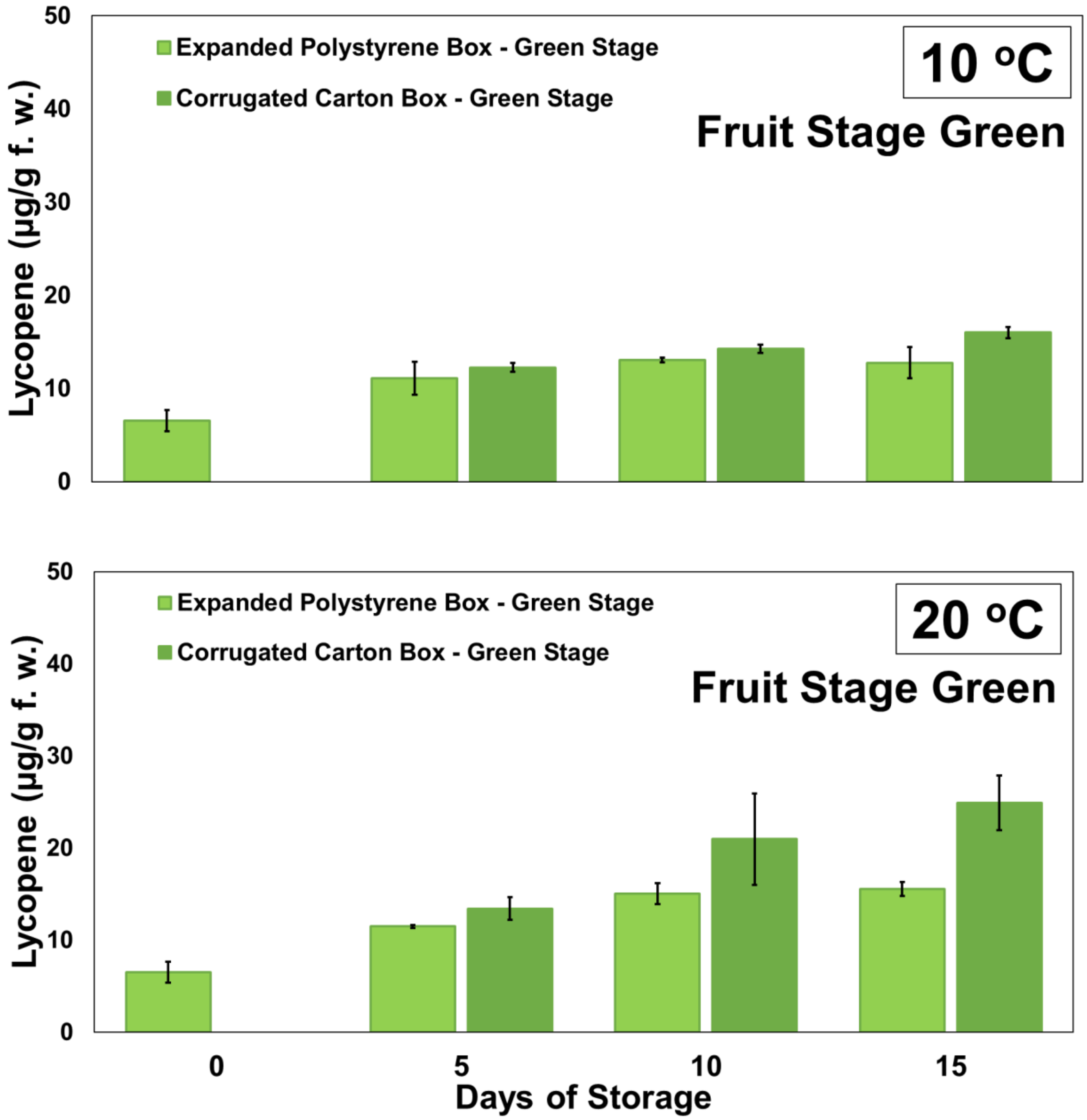


Figure 54. Lycopene content (μg/g f.w.) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20^{o}C for 5, 10 and 15 days.

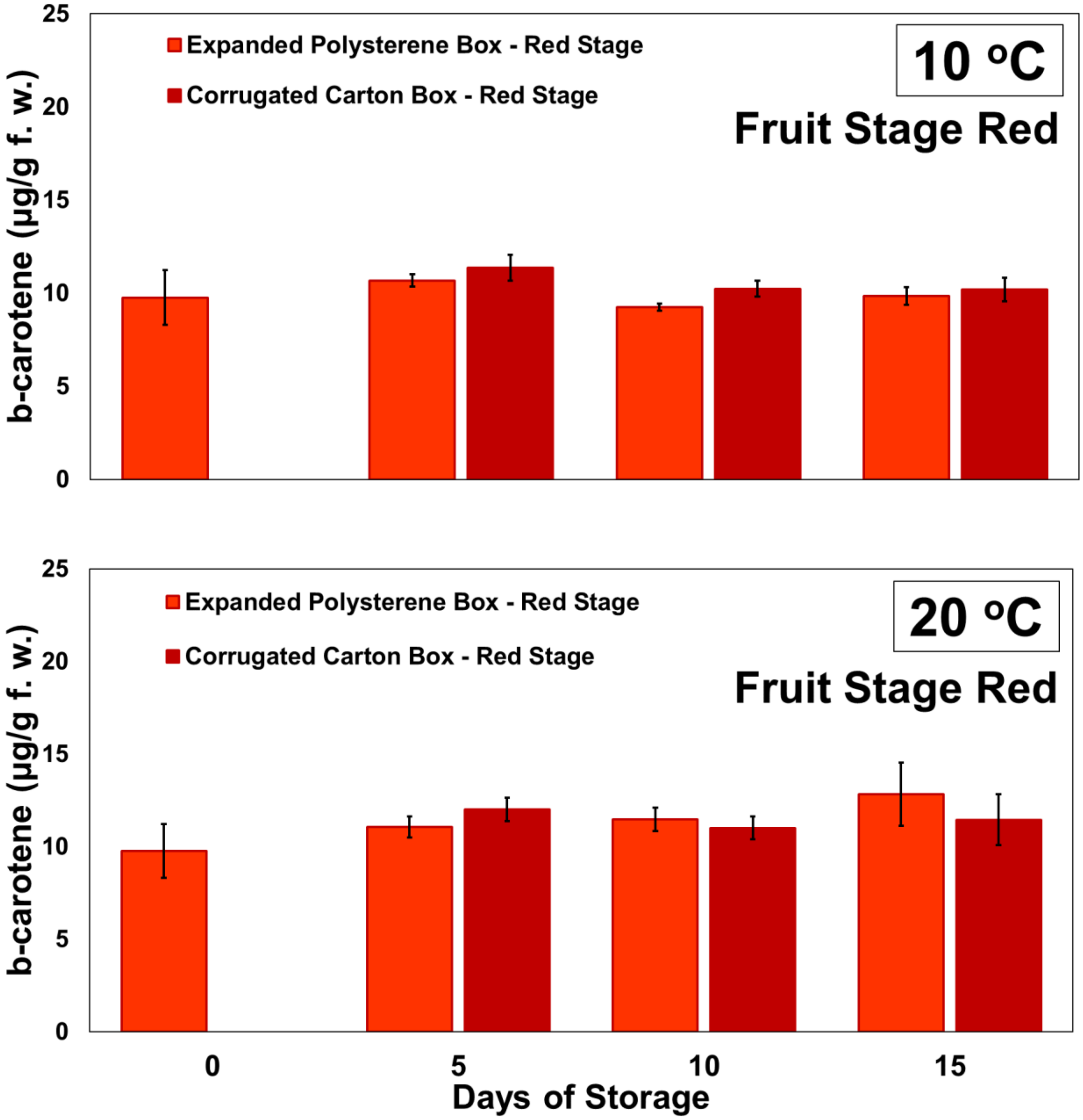


Figure 55. b-Carotene content (μg/g f.w.) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 5, 10 and 15 days.

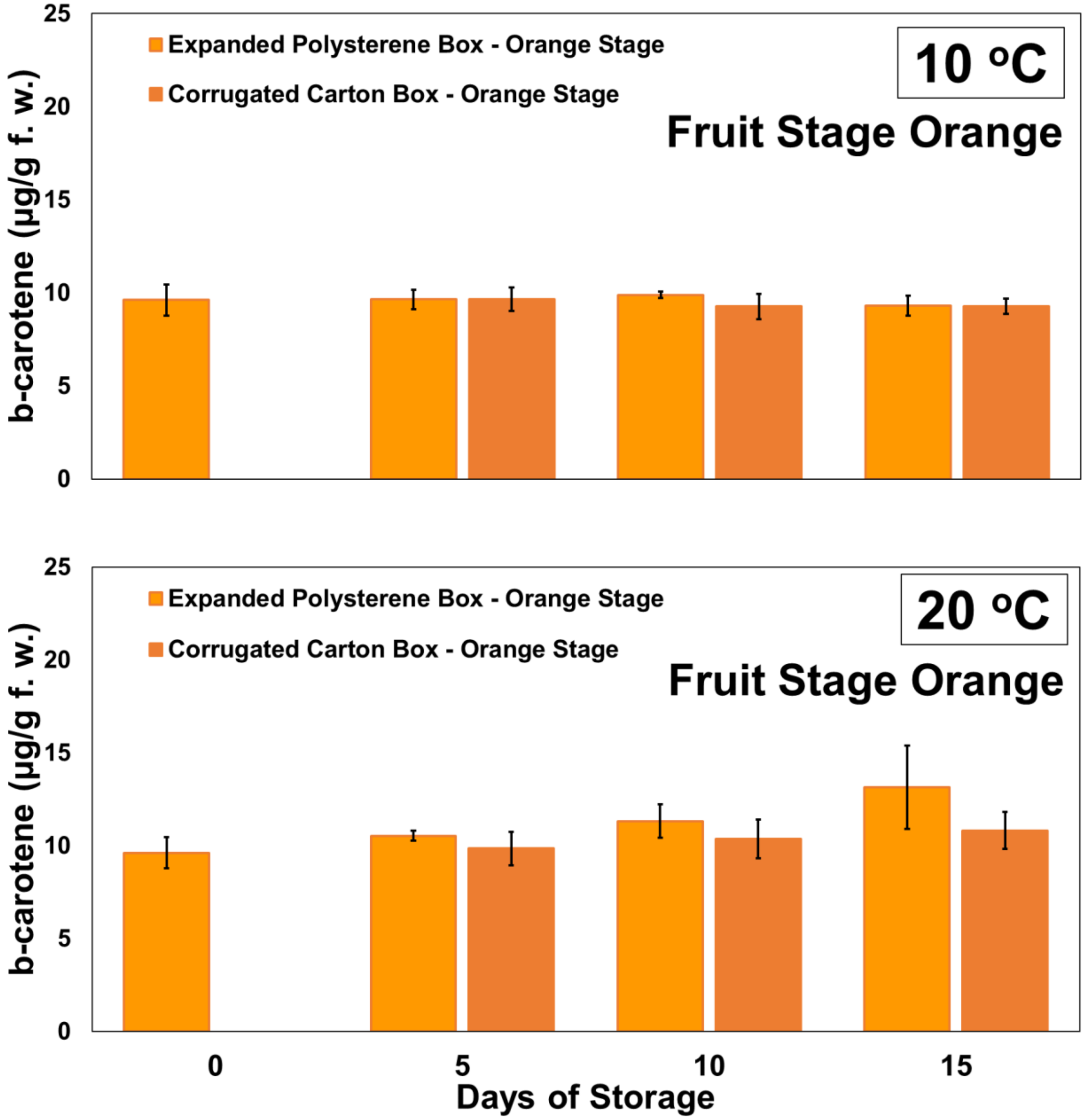


Figure 56. b-Carotene content (μg/g f.w.) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

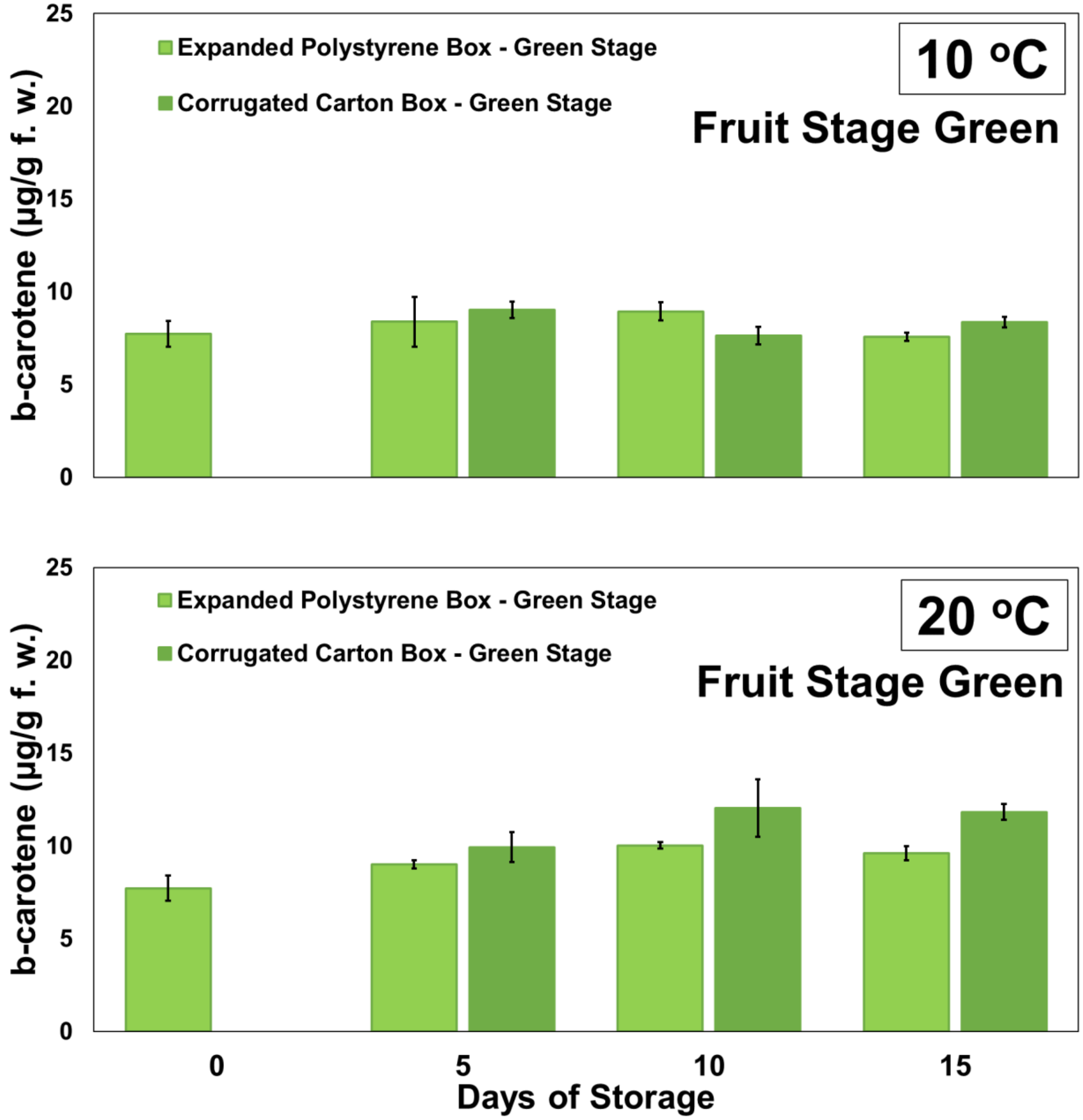


Figure 57. b-Carotene content (µg/g f.w.) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 5, 10 and 15 days.

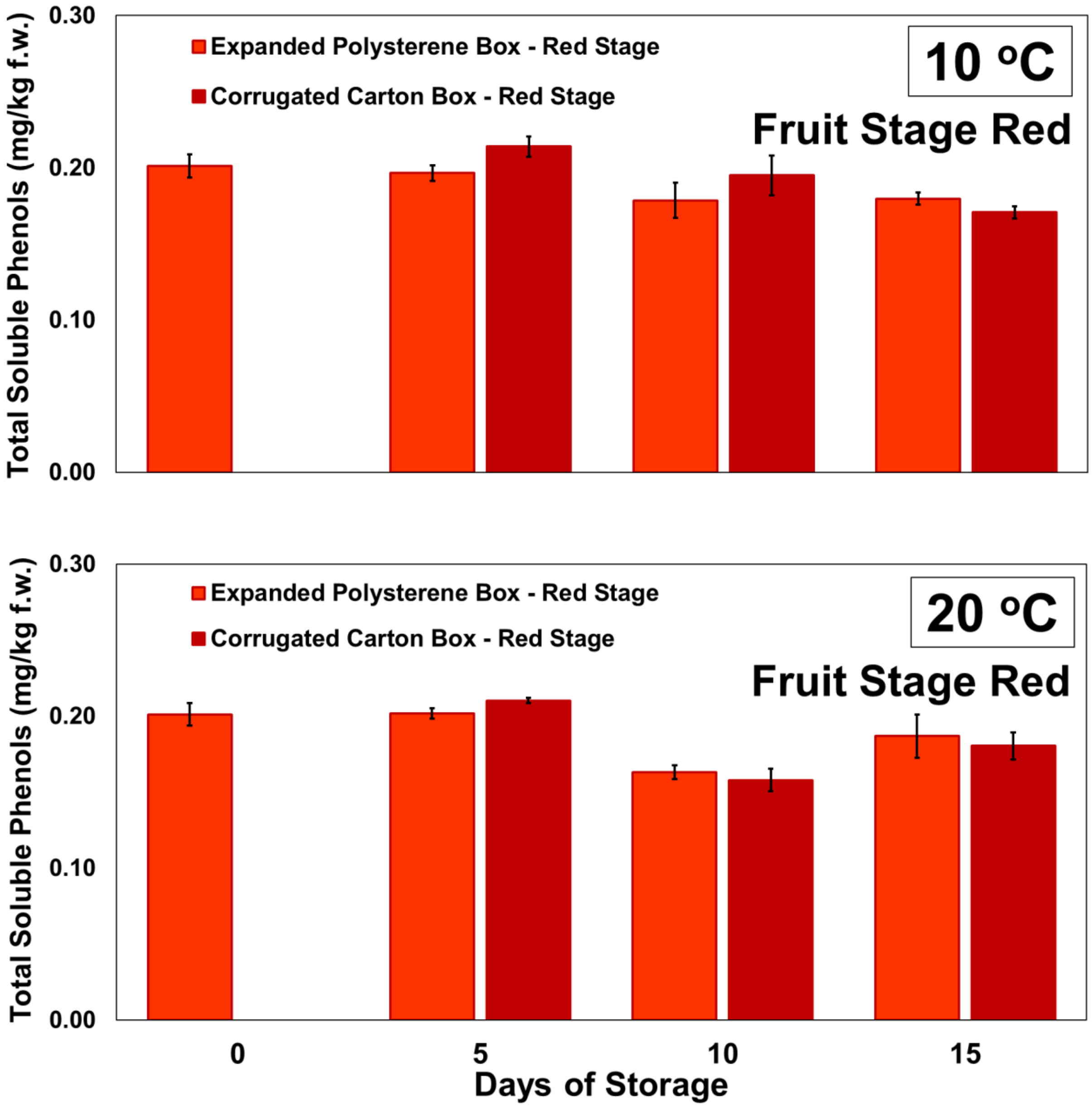


Figure 58. Total soluble phenols content (mg gallic acid equivalents/kg f.w.) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

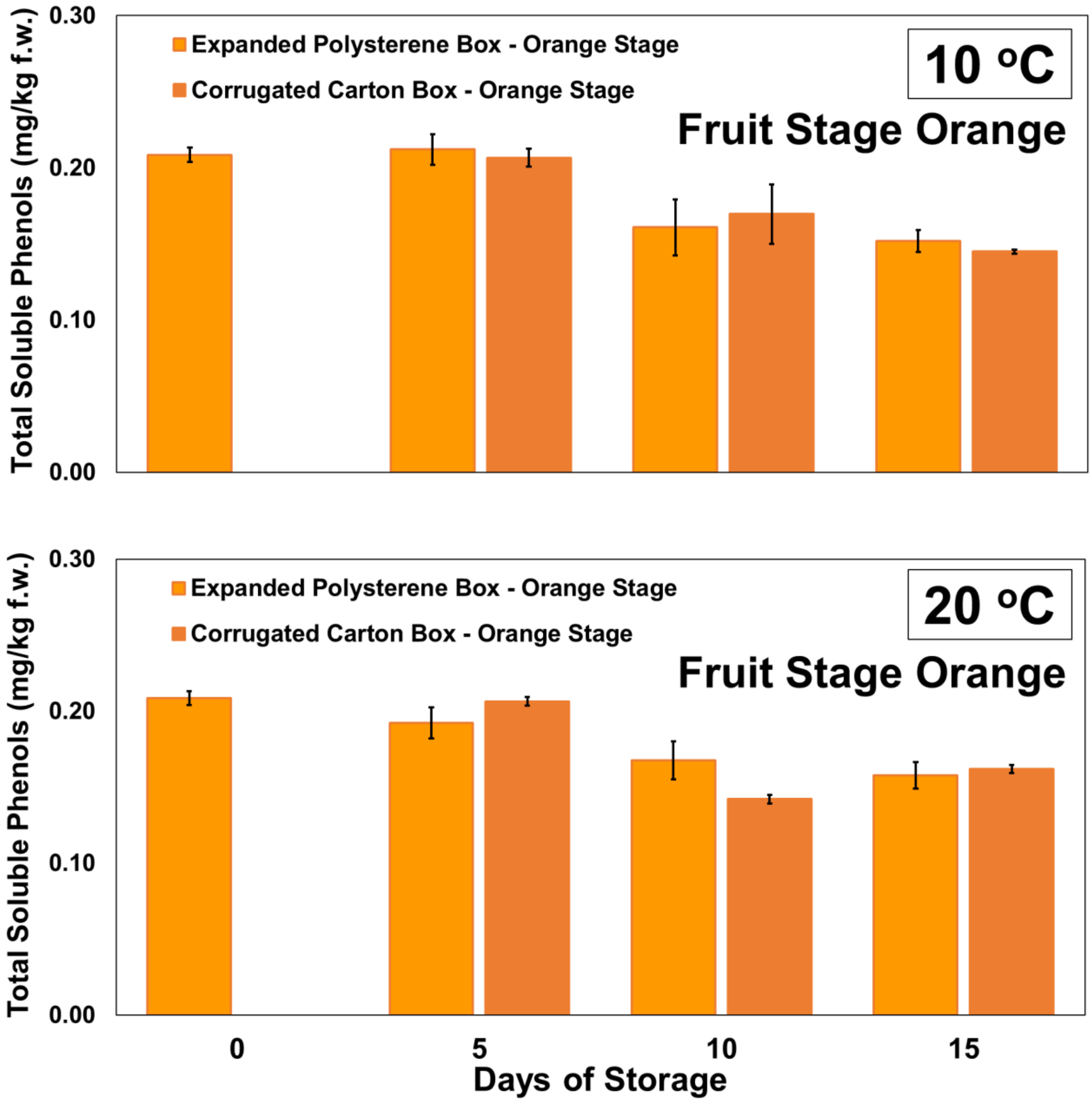


Figure 59. Total soluble phenols content (mg gallic acid equivalents/kg f.w.) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

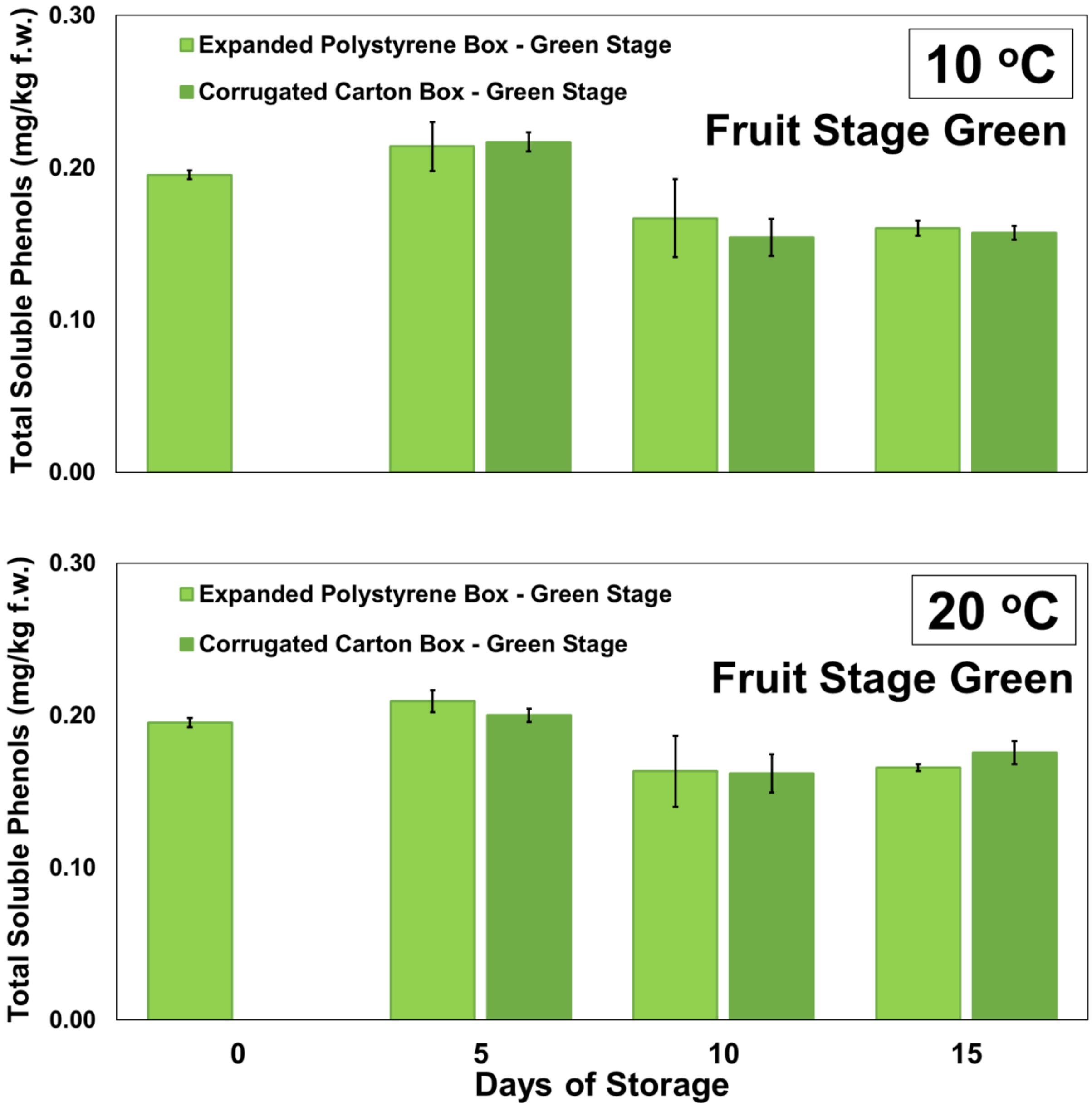


Figure 60. Total soluble phenols content (mg gallic acid equivalents/kg f.w.) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

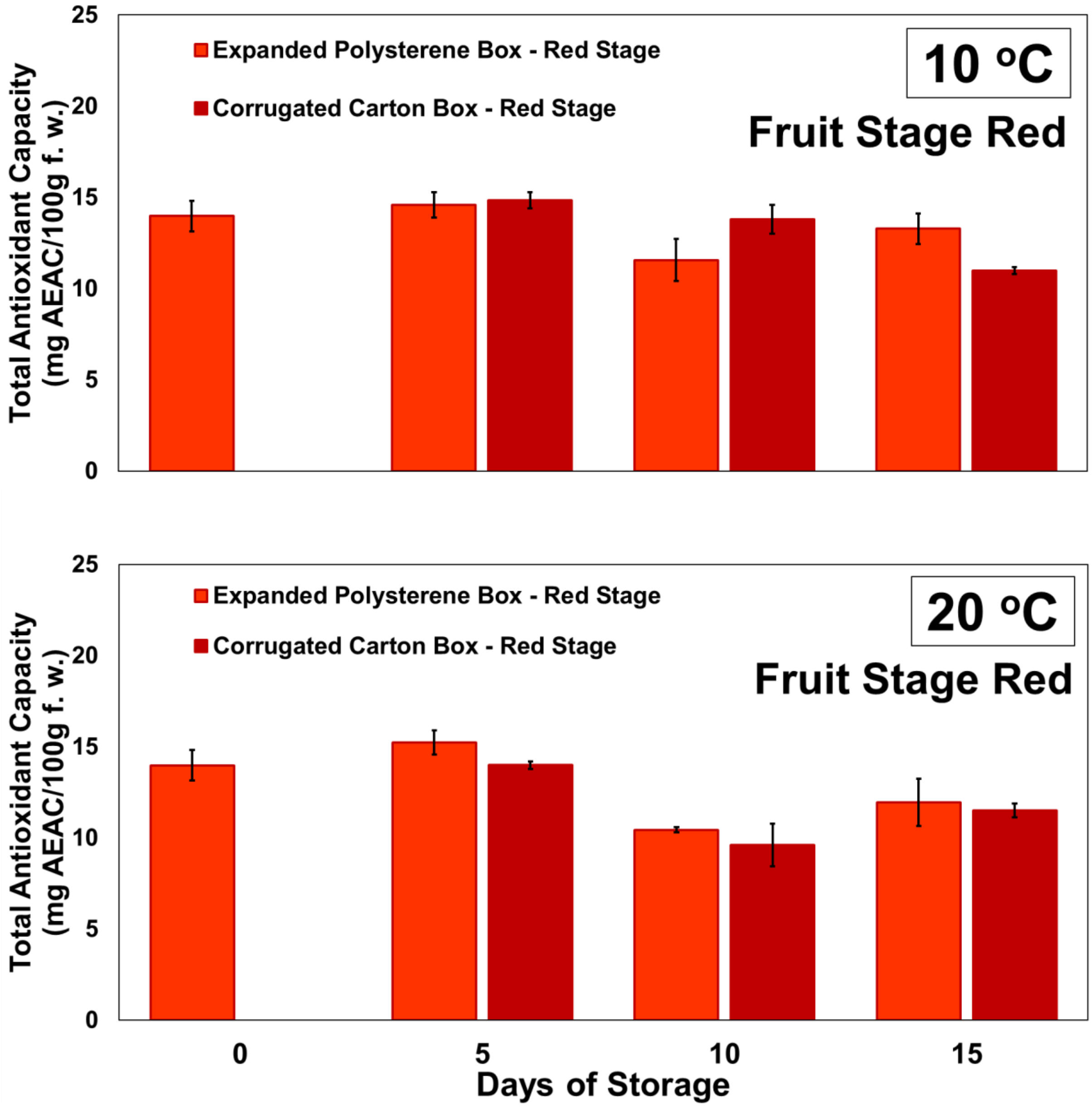


Figure 61. Total antioxidant capacity (mg ascorbic acid equivalents/100g f.w.) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

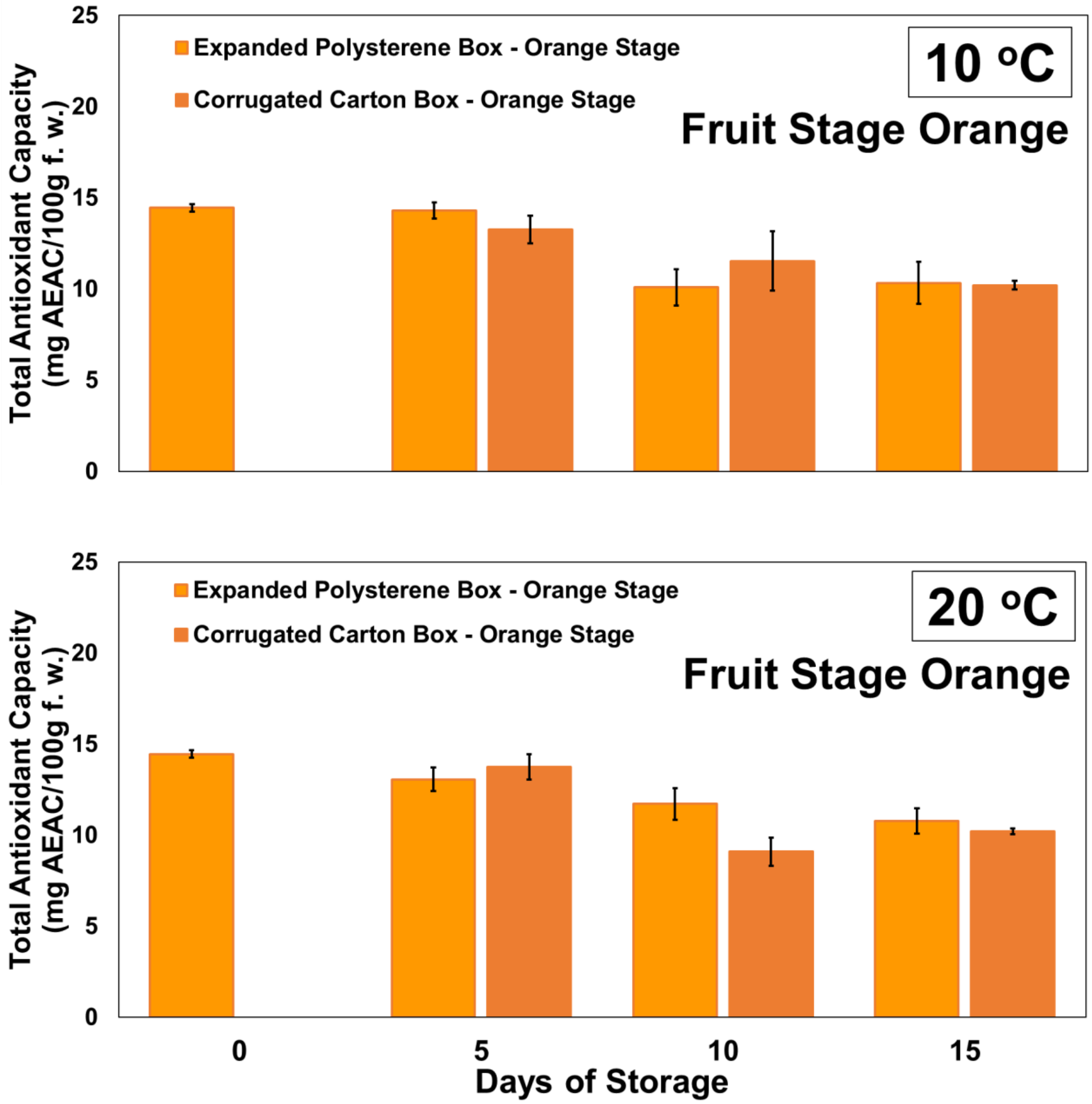


Figure 62. Total antioxidant capacity (mg ascorbic acid equivalents/100g f.w.) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 5, 10 and 15 days.

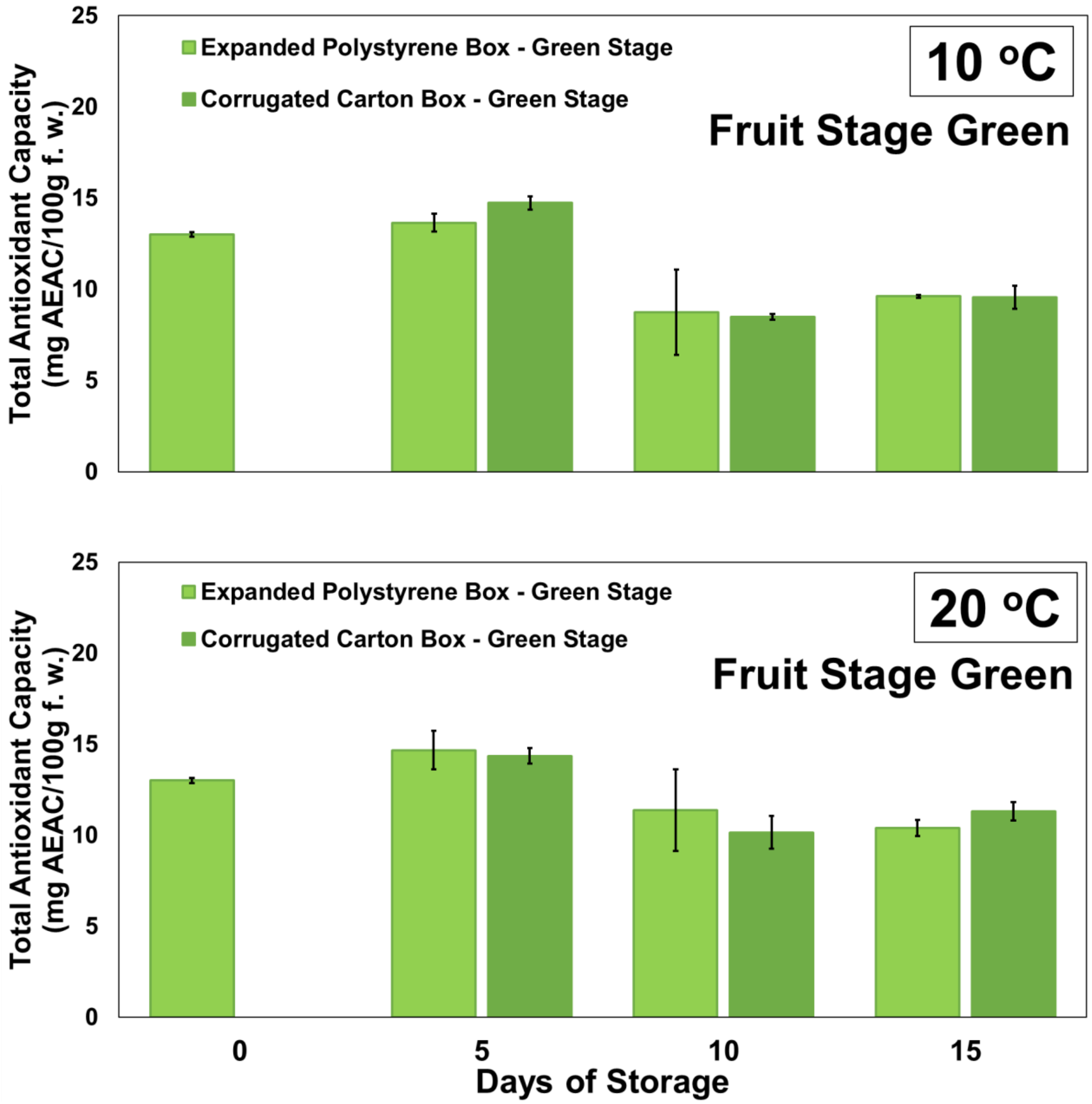


Figure 63. Total antioxidant capacity (mg ascorbic acid equivalents/100g f.w.) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 5, 10 and 15 days.

Report on the 2nd study of tomato storage in EPS package

Abstract

Three hundred fifty tomato fruits were harvested from the commercial greenhouse of 'AGRIS SA' and were transferred within the same day in the Lab of Vegetable Crops, AUTH. Upon the arrival of fruits at the lab, they were immediately sorted in 3 distinct ripening stages, according to their color; in red (ripe stage), orange (mid-ripe stage) and green (immature stage). All the tomato fruits were weighed, had their color measured at two opposite sites on the equatorial zone and 9 of them were frozen immediately for analysis, representing Day 0 samples. The remaining tomato fruits of each one ripening stage were packaged either in EPS or corrugated carton boxes in 3 replicates, with 9 fruits per replication. All the tomato fruits in the EPS and corrugated carton fruit packing boxes were kept at 10^{o}C for one day to ensure a uniform temperature inside all packages. Data loggers were also placed inside the packages to record the temperature and the relative humidity conditions. The packages were transferred into two different storage temperatures, 10 and 20^{o}C. Every 5 days, three tomato fruits from each package were sampled. The weight and the color of each fruit were measured and they were frozen for nutritional composition analysis. The nutritional components determined were the dry matter, the pH, the titratable acidity, the total antioxidant capacity, as well as the total soluble solids, the total soluble phenols, the total carotenoids, the total chlorophyll, the b-carotene and lycopene content. Although at both storage temperatures, similar temperature levels were recorded inside the EPS packages and the corrugated carton boxes, the relative humidity was always maintained at higher levels with the lowest deviation in the EPS packages, due to the insulation that is offered by such a closed package system, in contrast to the open corrugated carton packages where a severe variation in the relative humidity was daily recorded. According to the results, it is concluded that the quality of the tomato fruits can be maintained in high level, during storage in EPS packaging systems, given that the fresh weight loss of tomatoes is as low as possible due to the reduced transpiration of the fruit in the closed EPS environment. At the same time, neither firmness nor color changes are greater in tomatoes placed in the EPS package, implying that such a packaging system offers an insulation as confirmed by the high relative humidity levels and its low fluctuation during storage, but at the same time permits the gas exchange with the external atmosphere and especially the escape of ethylene, which is considered as a gas ripening

hormone. Apart from the advantages of the use of EPS in the storage of tomatoes at both 10 and 20^{o}C, in maintaining the weight of the fruit, also the nutritional composition inside the tissue was not altered in a different way than fruits stored in uncovered carton boxes and particularly in terms of dry matter, soluble solids, titratable acidity, carotenoids, b-carotene, lycopene, phenolics and antioxidants. Summarizing the above, it is concluded that EPS packaging of tomatoes can ensure optimal quality preservation of tomatoes harvested either at the red ripe or even at the orange and green stage for a period even beyond the 15 days at 10 or 20^{o}C. Special care should be paid after 3 weeks of storage of tomatoes at 10^{o}C though, in terms of ensuring the periodical aeration of the packages, in order to avoid the extreme increase of relative humidity in the packaging atmosphere, which in turn may result in fungal infestations.

Materials and methods

Three hundred fifty tomato fruits (cv. Beef Bang) were harvested from the commercial greenhouse of 'AGRIS SA' and were transferred within the same day in the Lab of Vegetable Crops, AUTH. Upon the arrival of fruits at the lab, they were immediately sorted in 3 distinct ripening stages, according to their color; in red (ripe stage), orange (mid-ripe stage) and green (immature stage). All the tomato fruits were weighed, had their color measured at two opposite sites on the equatorial zone and 9 of them were frozen immediately for analysis, representing Day 0 samples. The remaining tomato fruits of each one ripening stage were packaged either in EPS or corrugated carton boxes in 3 replicates, with 9 fruits per replication. All the tomato fruits in the EPS and corrugated carton fruit packing boxes were kept at 10oC for one day to ensure a uniform temperature inside all packages. Data loggers were also placed inside the packages to record the temperature and the relative humidity conditions. The packages were transferred into two different storage temperatures, 10 and 20^{o}C. Every 5 days, three tomato fruits from each package were sampled. The weight and the color of each fruit were measured and they were frozen for nutritional composition analysis. The nutritional components determined were the dry matter, the pH, the titratable acidity, the total antioxidant capacity, as well as the total soluble solids, the total soluble phenols, the total carotenoids, the total chlorophyll, the b-carotene and lycopene content.

Results

Temperature and relative humidity

The temperature in both EPS and carton packages remained steady at 10 ^{o}C and quickly rose from 10 to 20^{o}C, after being transferred to the high storage temperature (Fig. 15&16).

At both storage temperatures, no difference between EPS packages and corrugated carton boxes was recorded. Apparently, the great void volume in the package and the low respiration rate of tomato fruits prevented from the increase of air temperature in EPS. The mean temperatures recorded in the packages that were stored at 10 and 20^{o}C, respectively, were: 10.8 and 19.8^{o}C in EPS package and 10.5^{o}C and 19.8^{o}C in corrugated carton package, respectively, without significant variation from the average value, as indicated by the very low standard errors (<0.72^{o}C).

The relative humidity was more stable in the EPS packages that were stored at 10^{o}C (Fig. 17), followed by EPS packages at 20^{o}C (Fig. 18), while in the corrugated carton package, severe variation in the relative humidity was observed either at 10 or 20^{o}C (Fig 17&18). Higher relative humidity variation was observed at the 10^{o}C storage temperature in the open carton boxes, due to the continuous circulation of the air by the cooling, and in turn this last one contributed to the dehydration of the tomatoes placed in the corrugated carton package, resulting in a higher weight loss.

The average relative humidity levels recorded in the packages that were stored at 10^{o}C was as high as 98.7% in EPS package stored at 10^{o}C with a very low deviation (±1.2%), followed by corrugated carton package (92%) (Fig 17&18). EPS packaging preserved a high RH level (87.7%) during storage at 20^{o}C whereas the relative humidity recorded in the same temperature from data loggers placed in the corrugated carton packages revealed an extremely low average RH (64.7%) with a notably high deviation (11.2%) (Fig, 18). Generally, the daily relative humidity fluctuated severely during each day at 10^{o}C and was very low in 20^{o}C, with both conditions not be considered as ideal in postharvest storage of tomato fruits. However, although high relative humidity prevents weight loss, as described below, special attention should be given in tomatoes during storage at 10^{o}C in EPS, especially when no precautious antifungal treatment is implemented as in our case, because after the 20th day a couple of fruits showed symptoms of fungal infestation, which is favored by these high relative humidity levels inside the packaging atmosphere.

Weight loss

The weight loss of the tomato fruits is attributed to the respiration and transpiration processes that take place during storage. Both respiration and transpiration rates depend strongly on the storage temperature and perhaps even more to the relative humidity of the surrounding area of the tomatoes.

Tomatoes harvested at the red ripe stage and stored in EPS packages at 10^{o}C lost 0.3, 0.6 and 0.8% of their initial weight after 5, 10 and 15 days of storage, respectively (Fig. 19). Tomatoes harvested at the orange stage and stored in the above conditions (EPS, 10^{o}C) lost 0.4-0.9% weight (Fig. 20), whereas the weight loss of fruits that were harvested at the green stage reached 0.4- 1.0% after two weeks of storage at 10^{o}C in the EPS packaging (Fig. 21). Tomatoes harvested at the red, orange and green stage and packaged in open corrugated carton boxes suffered from significantly higher weight loss, comparing with the EPS packages ones, resulting in 1.3, 1.6 and 1.9% after 15 days of storage at 10^{o}C (Figs. 19-21). Storage of tomatoes in increased (room) temperature, 20^{o}C, significantly enhanced weight loss of tomato fruits harvested at all 3 different ripening stages, but was always higher, from 50 to 119%, greater in carton packages comparing to the corresponding fruits that were stored in EPS (Figs 19-21).

Firmness

The firmness of tomatoes harvested at the red ripe stage was 1.14 kg, those at the orange stage were 1.55 kg firm, whereas the green fruits had an even higher firmness of 1.93 kg (Figs. 22-24). Storage at 20^{o}C mostly affected orange and green stage harvested tomatoes. Indeed, fruits harvested at the red stage slightly softened during storage at either 10 or 20^{o}C after 2 weeks of storage, reaching 0.84-1.02 kg, without significant differences either among the two storage temperatures or between the two packages (Figs 22-24). On the other hand, orange and green stage harvested fruits reached 0.81-0.95 kg firmness, significantly lower than storage at 10^{o}C, but without notable differences between EPS or conventional carton packages.

Color

The color of the tomato fruits was measured on the equatorial zone of each fruit, with a Minolta CR-200 colorimeter. Different color parameters were determined, namely lightness (L*), chroma (C*) and hue angle (h^o).

Lightness (L*) describes the brightness of a tissue and takes values between 0 that corresponds to black color and 100 that corresponds to white. Lightness was lower in the red ripe fruits, comparing to orange and green ones, but only slightly changed during storage with no significant differences in fruits packaged in EPS or carton box or between the tomatoes stored in 10 or 20^{o}C (Figs 25-27).

Chroma (C*) represents the vividness (high values) or dullness (low values) of a color. During two weeks of storage at 10^{o}C, C* values increased in all fruits and as a result even the tomatoes that were harvested at the green stage finally obtained the C* values that the red ripe fruits initially had (Fig. 28-30). Indeed, it is worth mentioning that fruits packaged in EPS always had significantly higher C* values than the ones that were placed in open carton box, implying an advance ripening process perhaps due to the presence of a low amount of ethylene inside the EPS package. During storage at 20^{o}C, chroma of orange and green tomatoes increased substantially with the first 5 days of storage and only slightly thereafter, without significant differences between the two packages (Figs. 28-30).

Hue angle describes the hue of the color and each degree corresponds to a specific color (0^o for red, 90^o for yellow, 180^o for green, 270^o for blue). Hue angle was lowest at the red ripe tomatoes and highest at the green ones (Figs. 31-33). During storage at both temperatures, hue angle values decreased in orange and green fruits, but it never became as low as the red ripe tomatoes even after 15 days, implying an incomplete ripening of these tomatoes (Fig. 30).
However, storage at 20^{o}C induced an advance ripening process of all tomatoes, implying that after 2 weeks, all tomatoes were of the same red color (Figs 31-33), as also confirmed by the photos 11-15. No significant differences were found between EPS and carton packages.

Nutritional quality

Total soluble solids content (SSC) includes all sugars and organic acids that are responsible for the flavor in vegetables. At harvest SSC was 4.72, 4.97 and 5.03% in red ripe, orange and green tomatoes, respectively and were showed only minimal variation during storage without dropping lower than 4.43% (Fig. 34-36).

Dry matter of tomatoes from all ripening stages at harvest was 5.2-5.4% and was not affected during storage either by the temperature or by the packaging system (EPS or open carton box), remaining almost unchanged up to 15 days of storage (Figs. 37-39).

During the two weeks of storage, pH of tomato fruits was fluctuating from 4.0- 4.3, without significant differences either between the two temperatures or the two packages, irrespectively of the ripening stage at harvest (Figs. 40-42). In all cases, 0.3 units of pH change cannot be considered as a significant nutritional change and neither can be perceived by humans during consumption.

Titratable acidity (TA) is an index of organic acids concentration in tomato flesh, with high values often being associated with sourness of the fruit. Lower TA (0.07%) was observed in red ripe tomatoes, as anticipated, not being substantially different after 15 days of storage at both temperatures and packaging systems (Fig. 43). The pH of orange tomatoes decreased during storage at both temperatures without differences between EPS and corrugated carton box (Fig. 44). On the other hand, although a decrease of pH was also observed in tomatoes harvested at the green and stored in 10 or 20^{o}C, it never obtained the low values of red ripe tomatoes after two weeks, irrespectively or being packaged in EPS or carton box (Fig. 45).

Regarding the ratio soluble solids content/ titratable acidity (SSC/TA), which is an index of the human sense of the flavor of the tomato fruit, changes during storage were only observed in orange and green harvested tomatoes which can be explained by the increase of reducing sugars and the reduction of organic acids content (46-48). No significant differences between the EPS and open carton package were found in both storage temperatures.

Total chlorophylls decreased (data not shown) and carotenoids increased (Figs. 49-51) significantly especially in fruits of all three ripening stages stored at 20^{o}C, without notable differences between the ones placed in EPS or open corrugated carton boxes.

The increase of total carotenoid content was following the increase of lycopene content (Figs. 52-54) and b-carotene (Figs. 55-57), which are the two principal carotenoids that contribute to the total content. As anticipated, no difference between EPS and carton packages was found.

Phenols content was 0.20 μg gallic acid equivalents/ g fresh weight at harvest, not different between the three ripening stages and slightly decreased in all fruits stored at both temperatures and packages (Figs. 58-60).

The same pattern with total soluble phenols content was found in the antioxidant capacity of fruits, that was also slightly decreased but without being different between fruits of the two packaging systems (Figs. 61-63).

Conclusions

According to the above results, it is concluded that the quality of the tomato fruits can be maintained in high level, during storage in EPS packaging systems, given that the fresh weight loss of tomatoes is as low as possible due to the reduced transpiration of the fruit in the closed EPS environment. At the same time, neither firmness nor color changes are greater in tomatoes placed in the EPS package, implying that such a packaging system offers an insulation as confirmed by the high relative humidity levels and its low fluctuation during storage, but at the same time permits the gas exchange with the external atmosphere and especially the escape of ethylene, which is considered as a gas ripening hormone. Apart from the advantages of the use of EPS in the storage of tomatoes at both 10 and 20^{o}C, in maintaining the weight of the fruit, also the nutritional composition inside the tissue was not altered in a different way than fruits stored in uncovered carton boxes and particularly in terms of dry matter, soluble solids, titratable acidity, carotenoids, b-carotene, lycopene, phenolics and antioxidants. Summarizing the above, it is concluded that EPS packaging of tomatoes can ensure optimal quality preservation of tomatoes harvested either at the red ripe or even at the orange and green stage for a period even beyond the 15 days at 10 or 20^{o}C. Special care should be paid after 3 weeks of storage of tomatoes at 10^{o}C though, in terms of ensuring the periodical aeration of the packages, in order to avoid the extreme increase of relative humidity in the packaging atmosphere, which in turn favor fungal infestations.

Photo 16. Tomato fruits harvested from Agris SA and transferred to the facilities of the Lab of Vegetable Crops, AUTH within the same day, before being sorted into three distinct ripening stages.

Photo 17. Red ripe tomato fruits placed in EPS or open carton box before being transferred to 5 or 10^{o}C for 32 days.

Photo 18. Tomato fruits after 32 days of storage at 10^{o}C in EPS (A-C) or open carton boxes (D-F) after being harvested at the red ripe (A, D), orange (B, E) or green stage (C, F).

Photo 19. Tomato fruits after 32 days of storage at 20ºC in EPS (A-C) or open carton boxes (D-F) after being harvested at the red ripe (A, D), orange (B, E) or green stage (C, F).

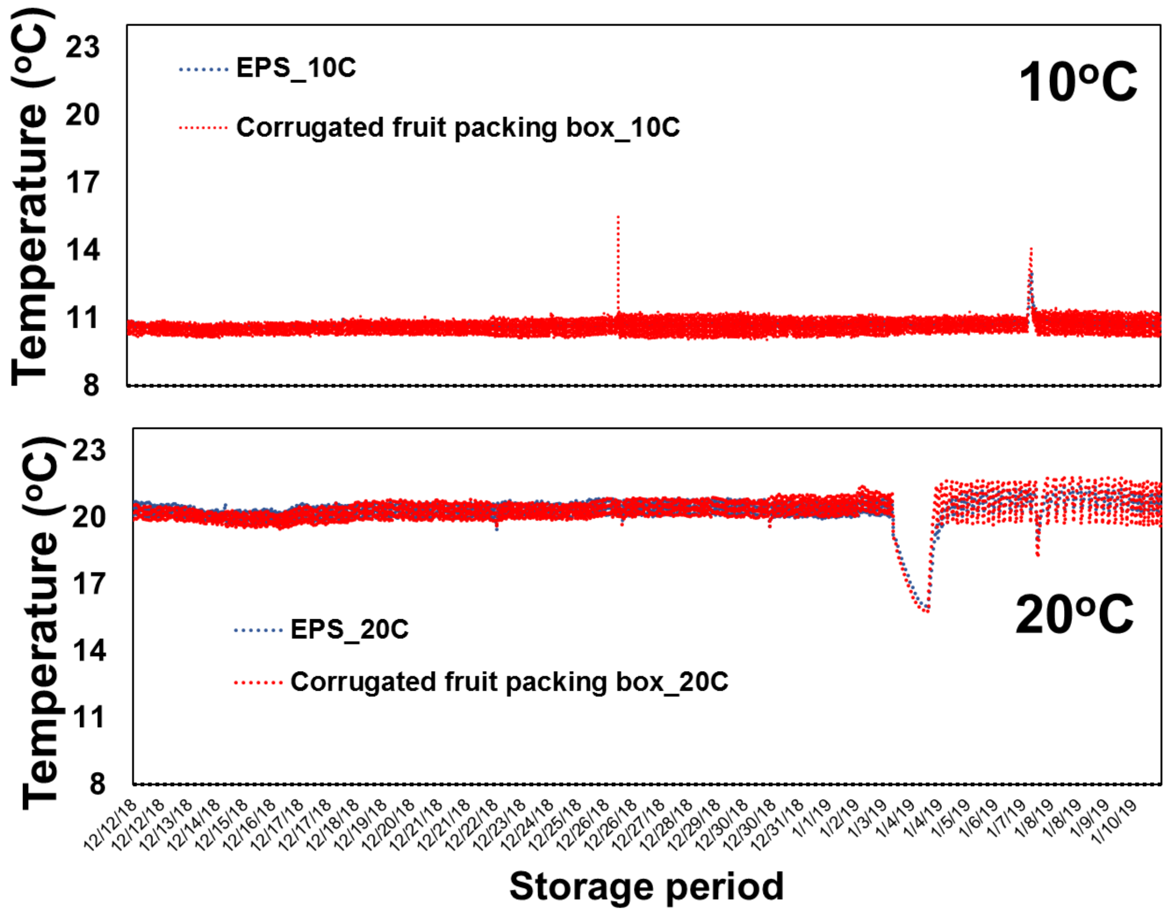


Figure 64. Temperature inside the EPS and the corrugated carton boxes of tomato fruits during storage at 10 and 20°C.

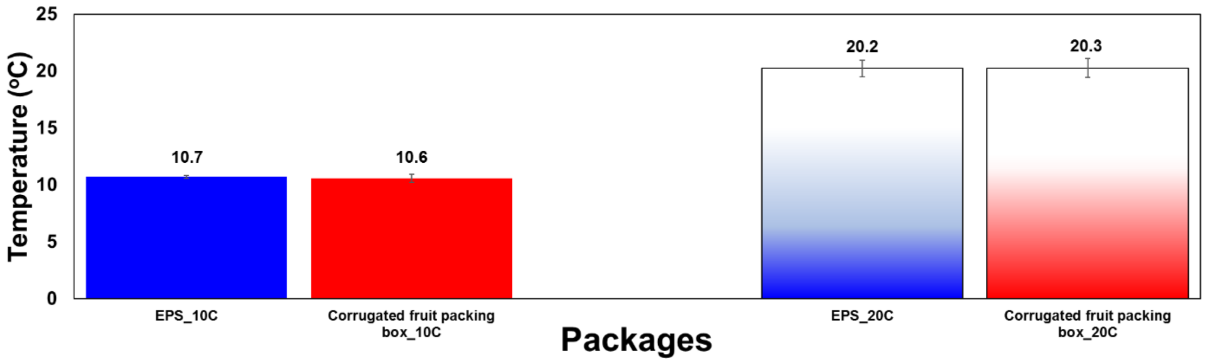


Figure 65. Mean temperature (± S.E.) inside the EPS and the corrugated carton boxes of tomato fruits during the whole period of storage at 10 and 20ºC.

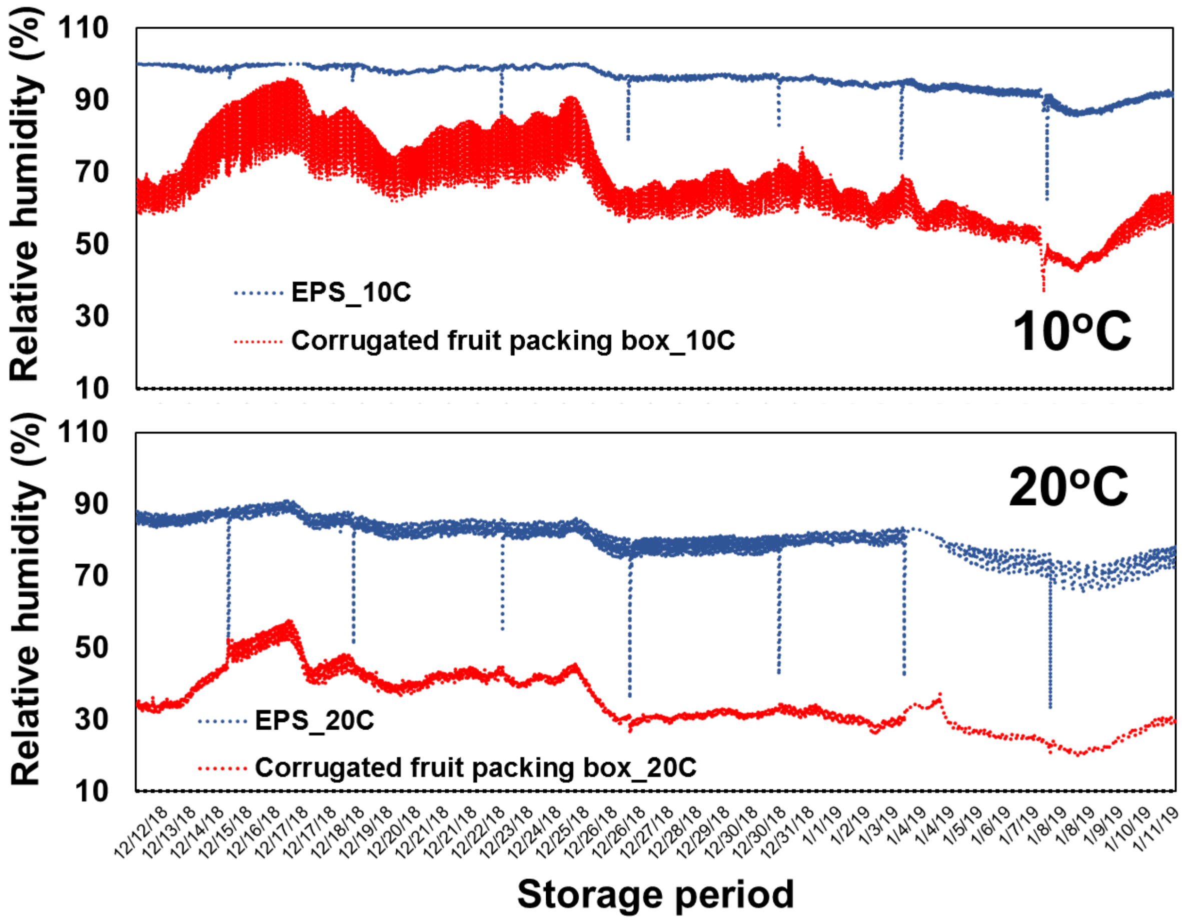


Figure 66. Relative humidity inside the EPS and the corrugated carton boxes of tomato fruits at 10 and 20°C.

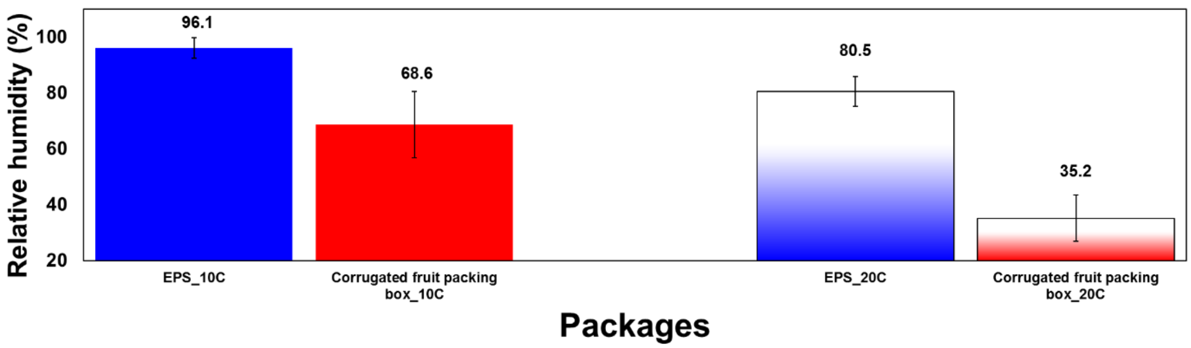


Figure 67. Mean relative humidity (± S.E.) inside the EPS and the corrugated carton boxes of tomato fruits during the whole period of storage at 10 and 20^{o}C.

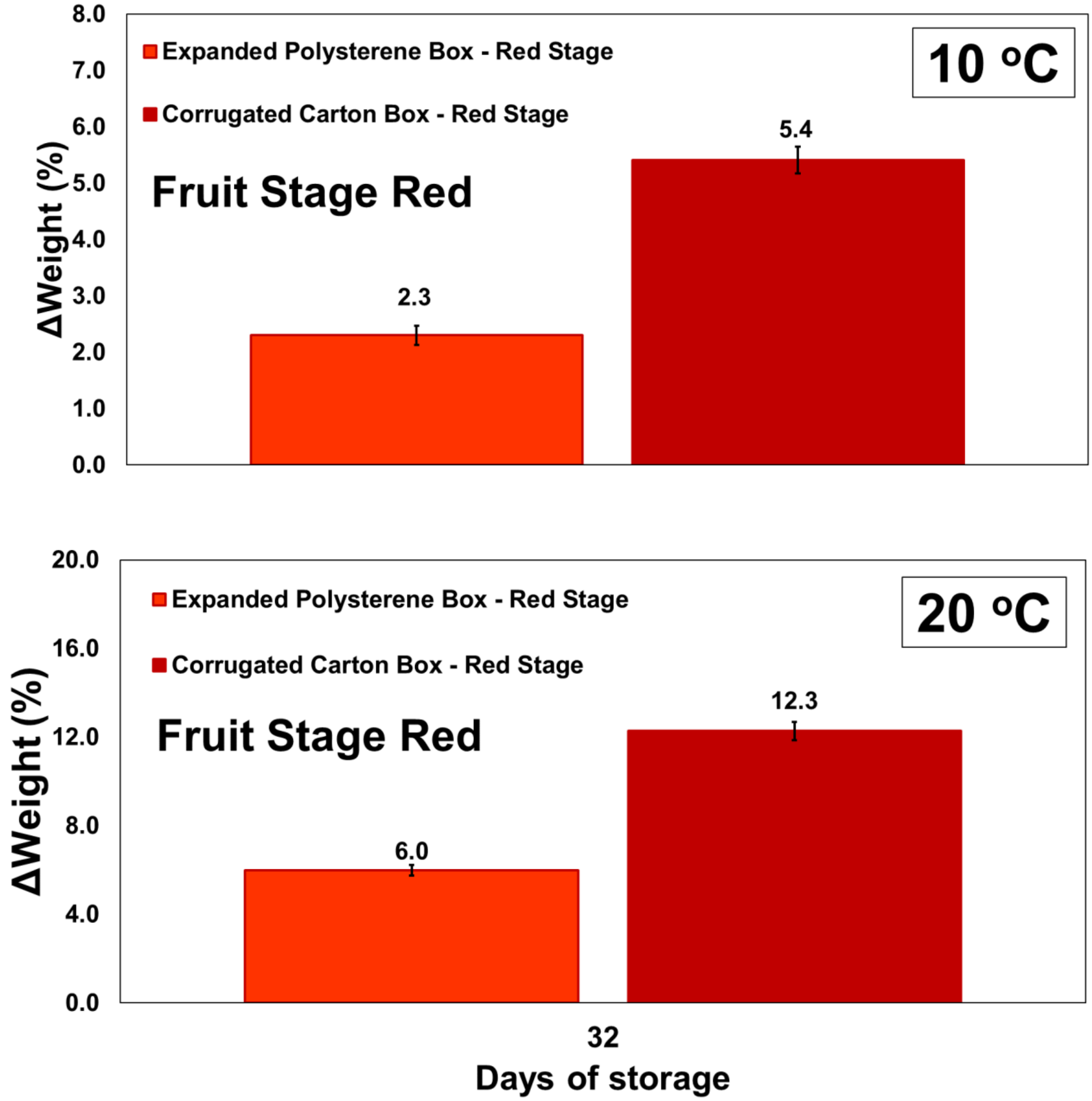


Figure 68. Δweight (%) (± S.E.) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 32 days.

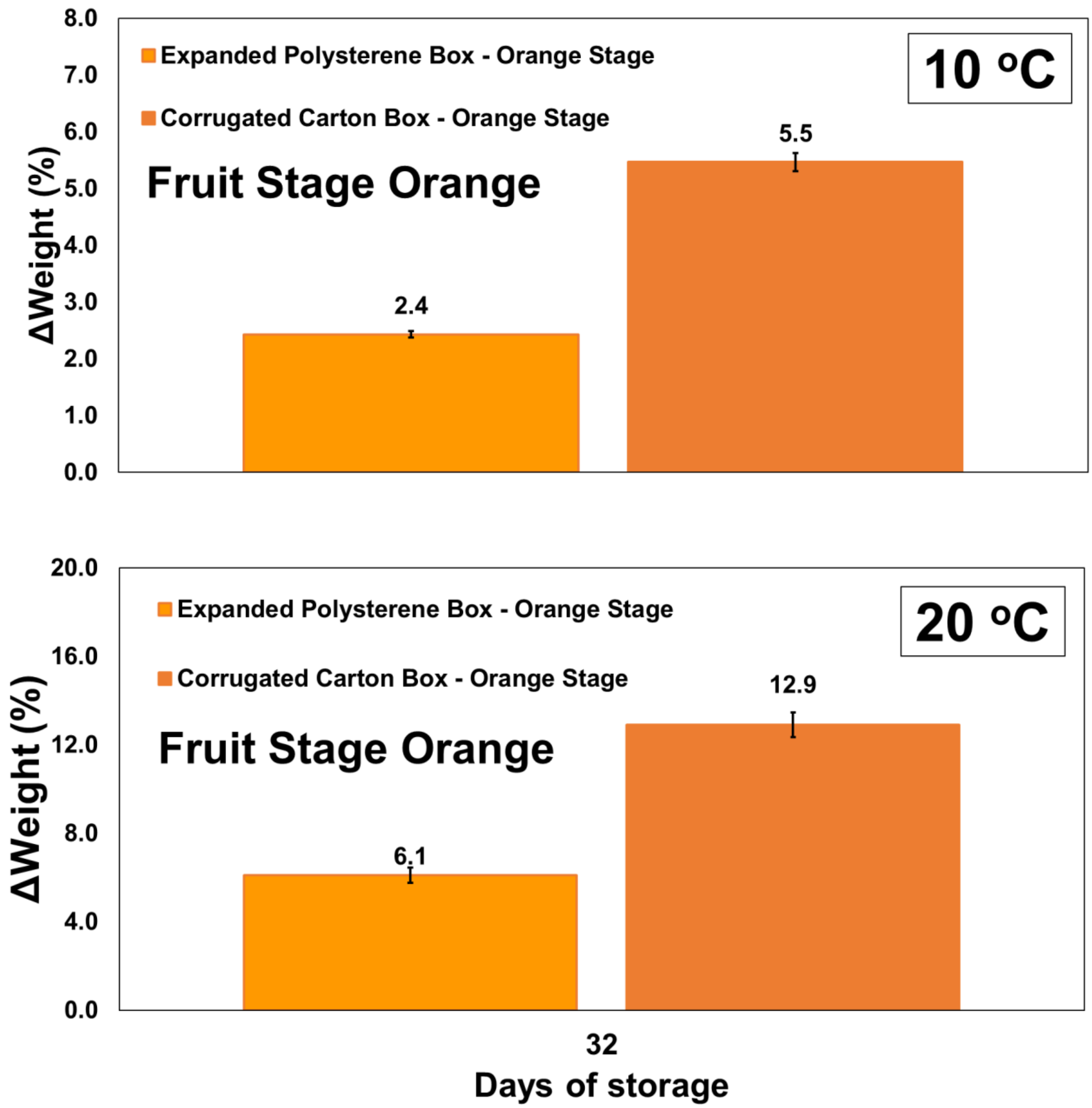
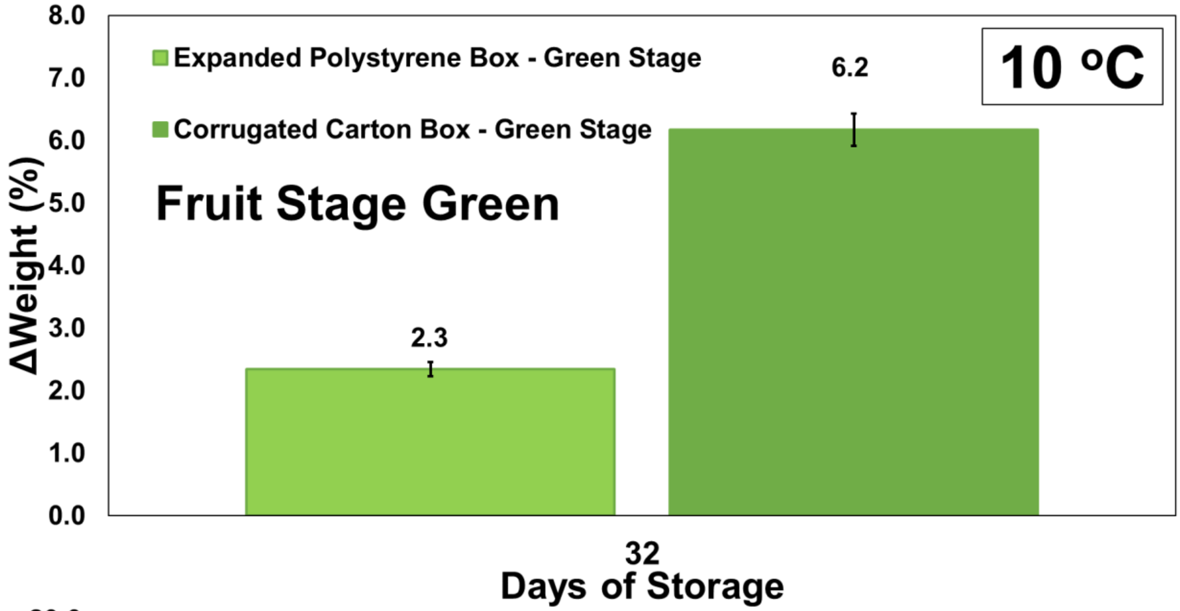


Figure 69. Δweight (%) (± S.E.) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 32 days.



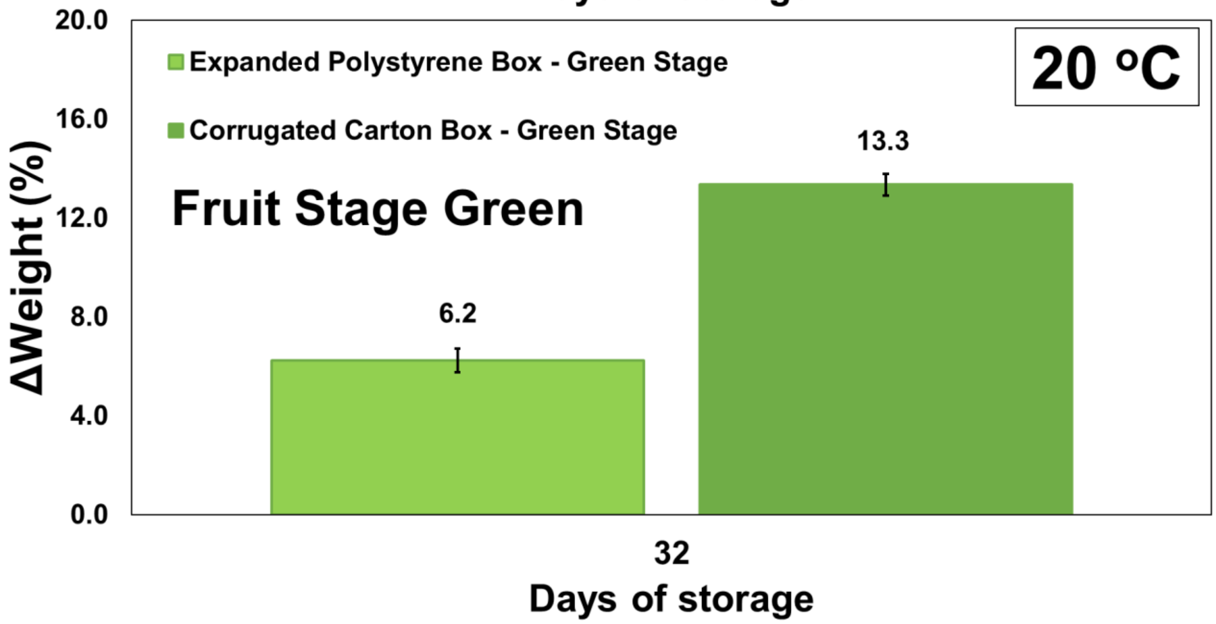


Figure 70. Δweight (%) (± S.E.) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

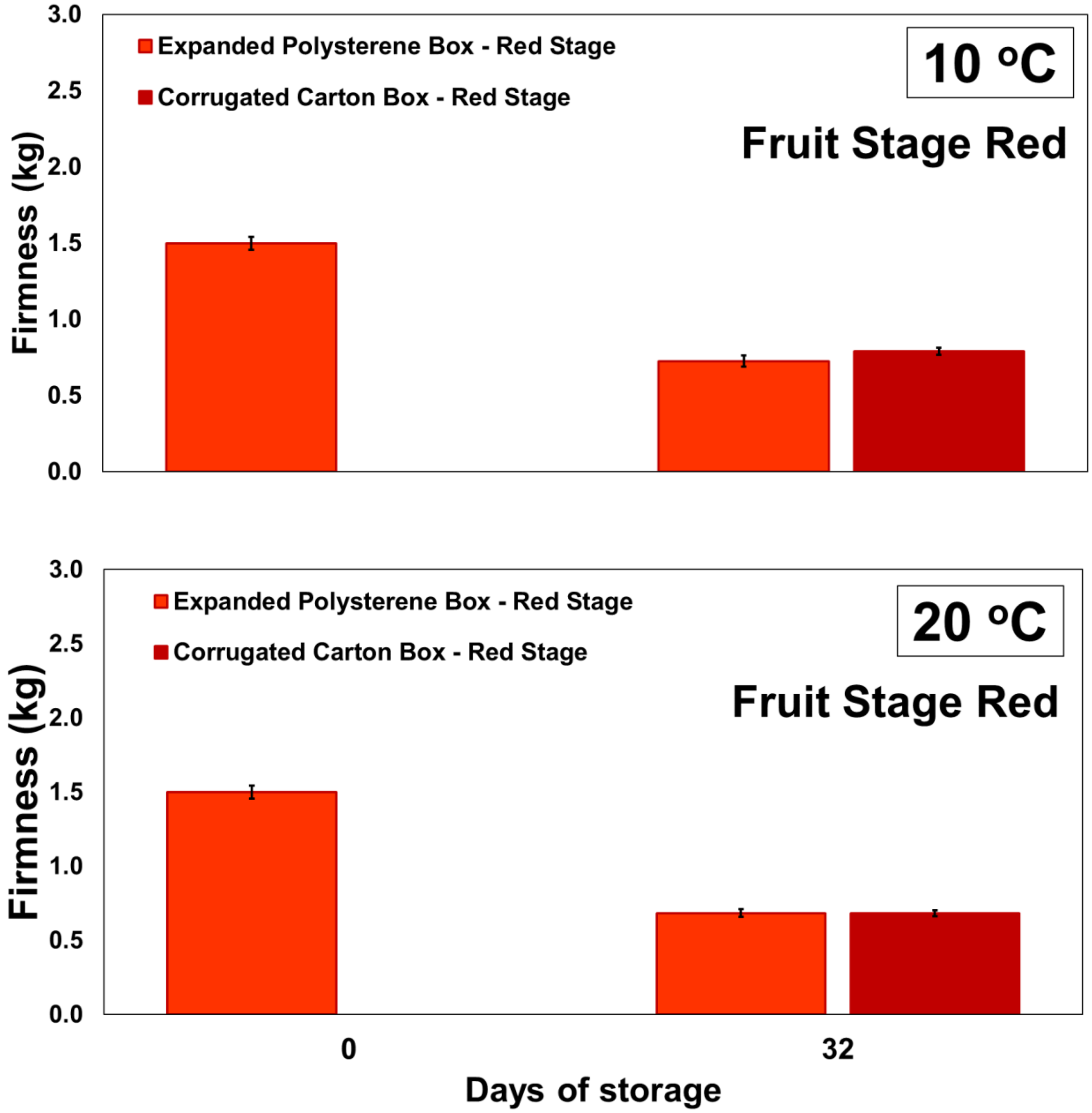


Figure 71. Firmness (kg) (± S.E.) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

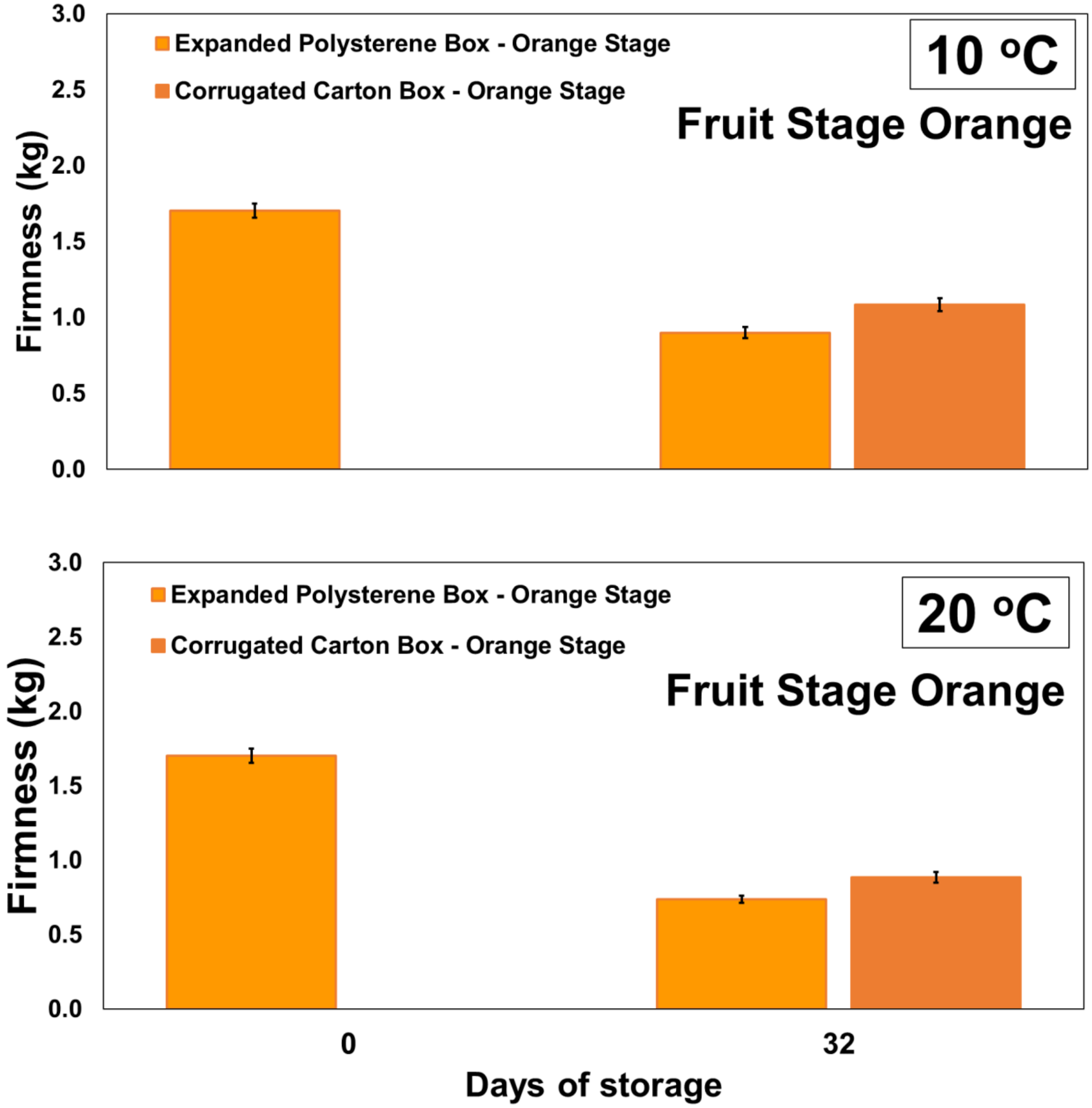


Figure 72. Firmness (kg) (± S.E.) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 32 days.

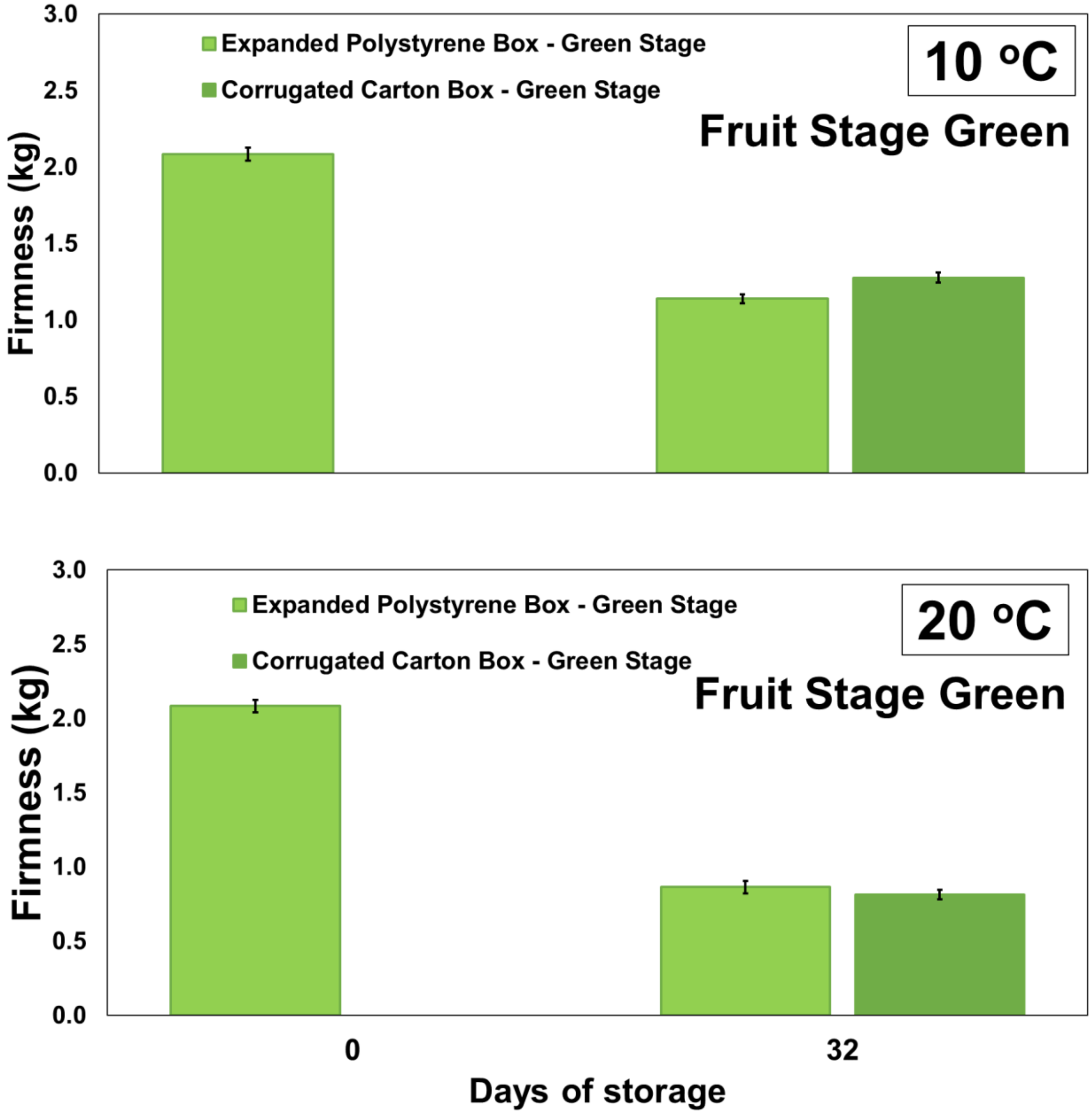


Figure 73. Firmness (kg) (± S.E.) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 32 days.

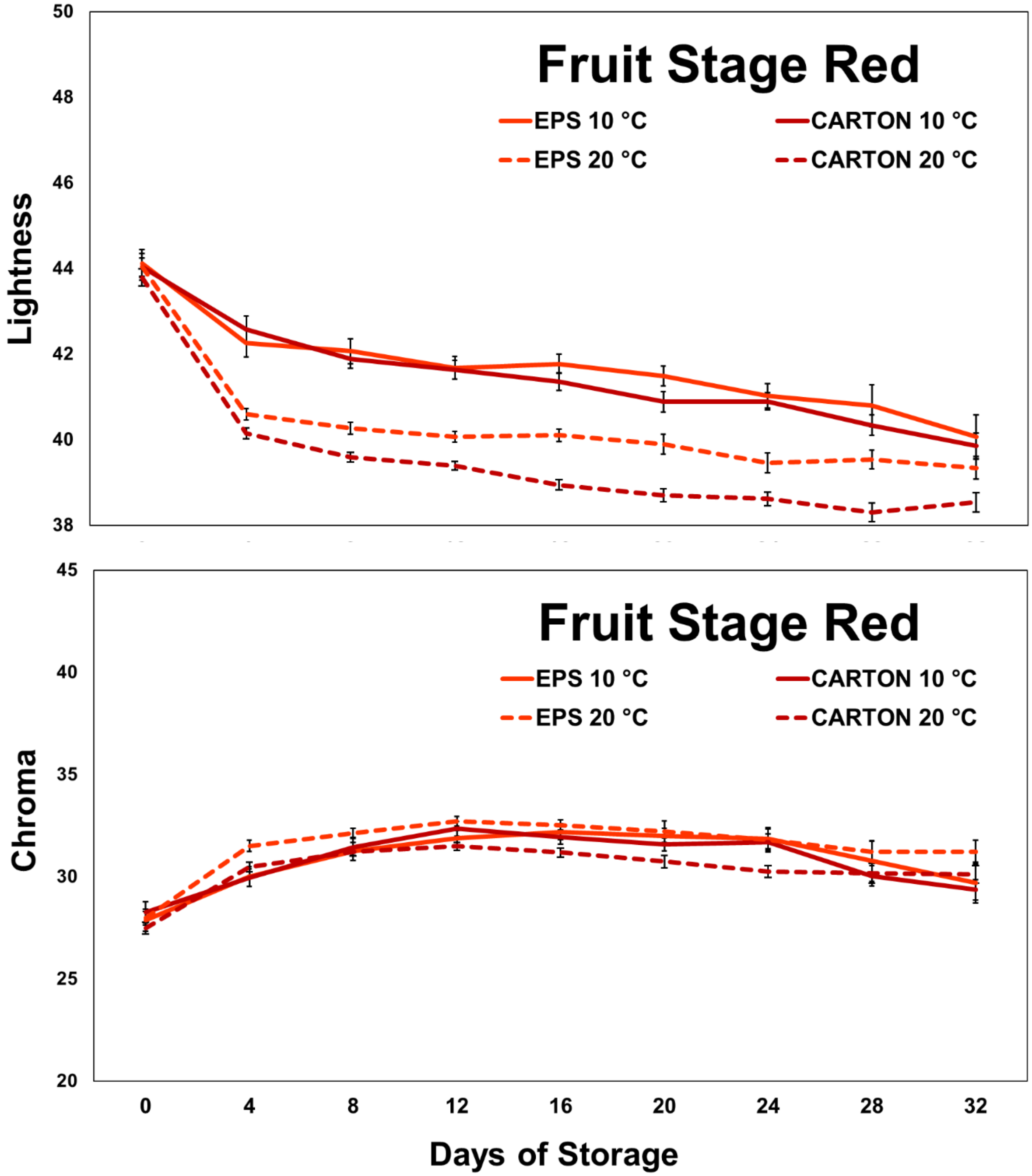


Figure 74. Lightness and chroma (± S.E.) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20^{o}C for 32 days.

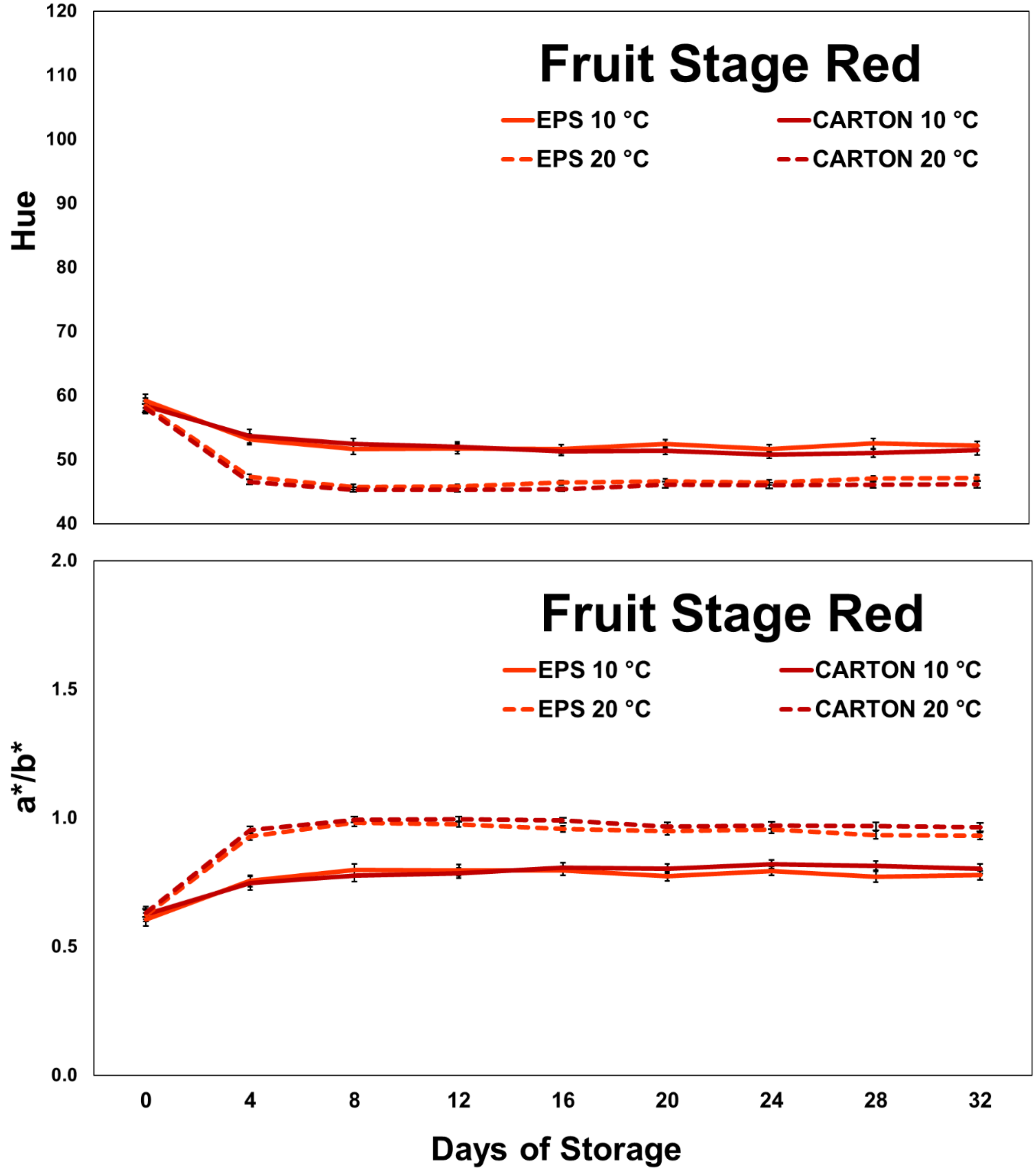


Figure 75. Hue angle and a/b (± S.E.) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

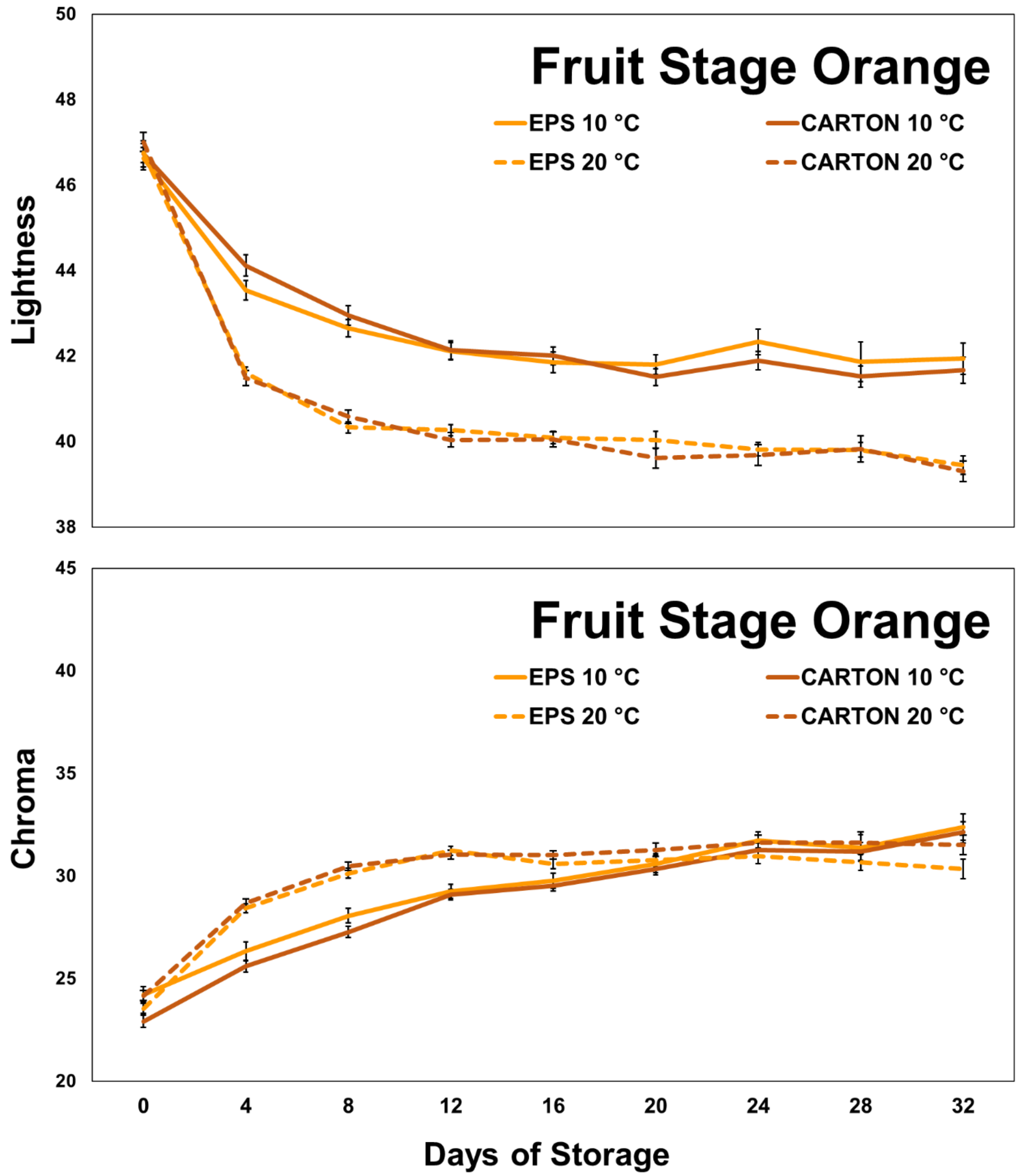


Figure 76. Lightness (± S.E.) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

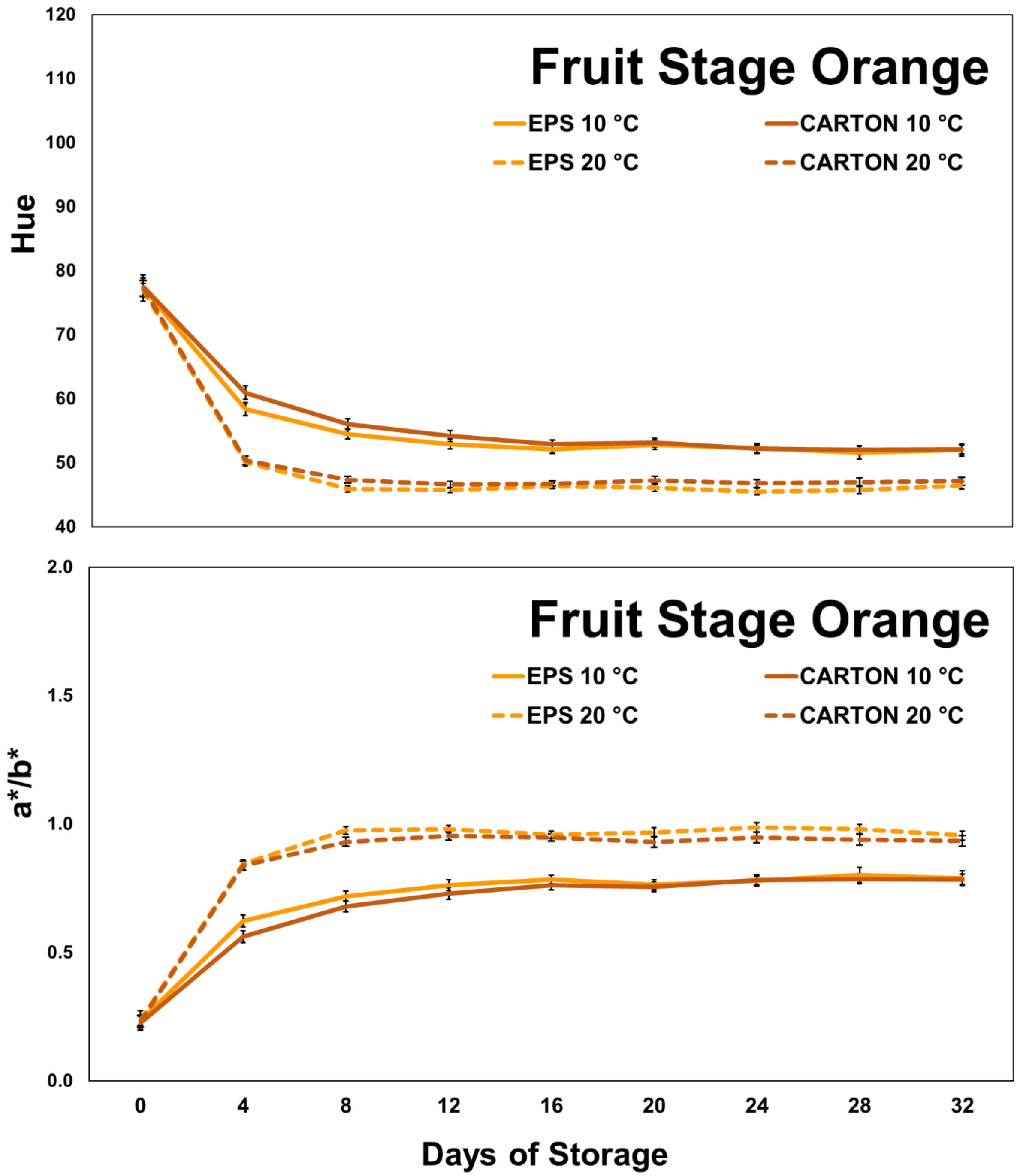


Figure 77. Hue angle and a/b (± S.E.) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20^{o}C for 32 days.

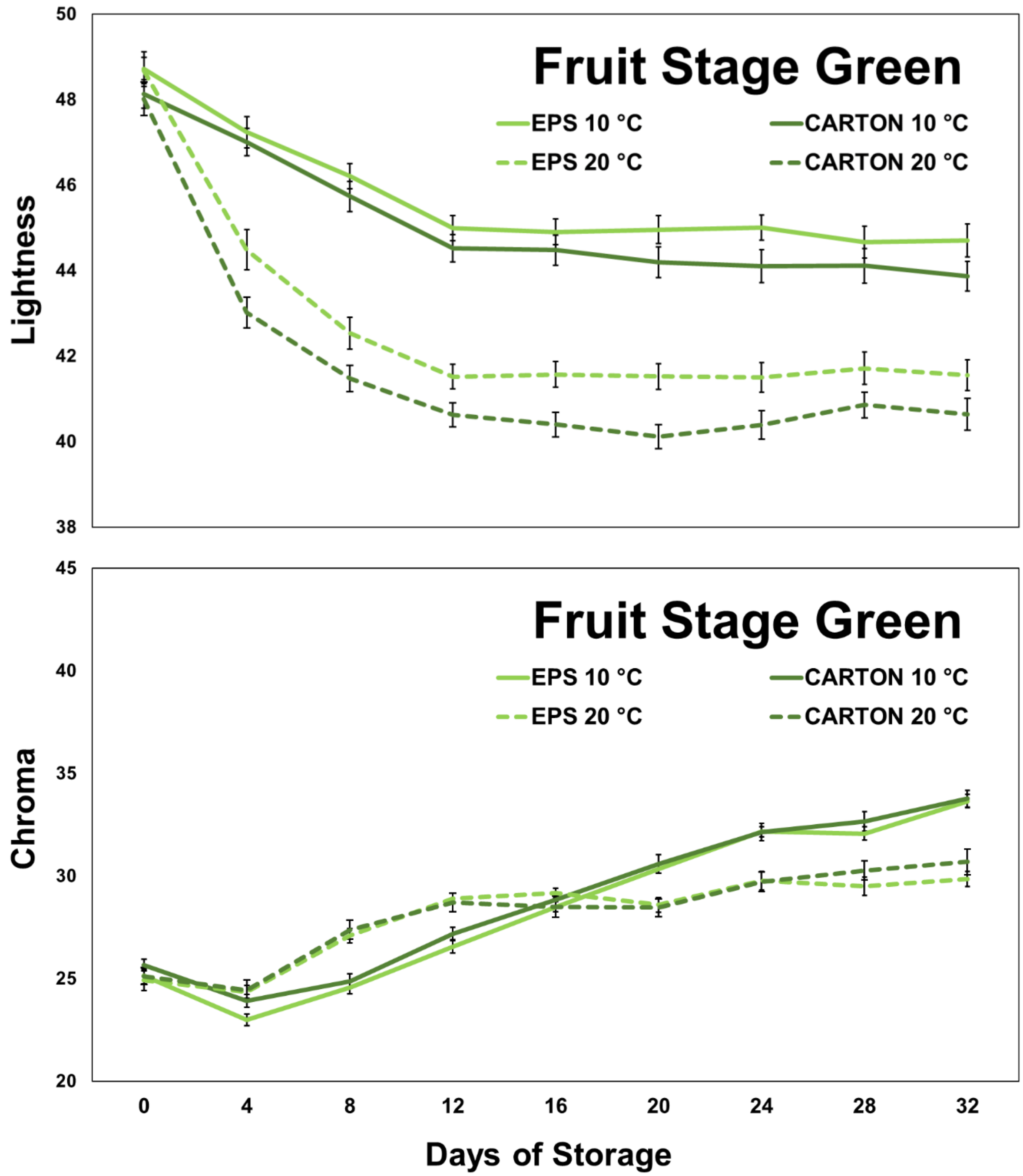


Figure 78. Lightness (± S.E.) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

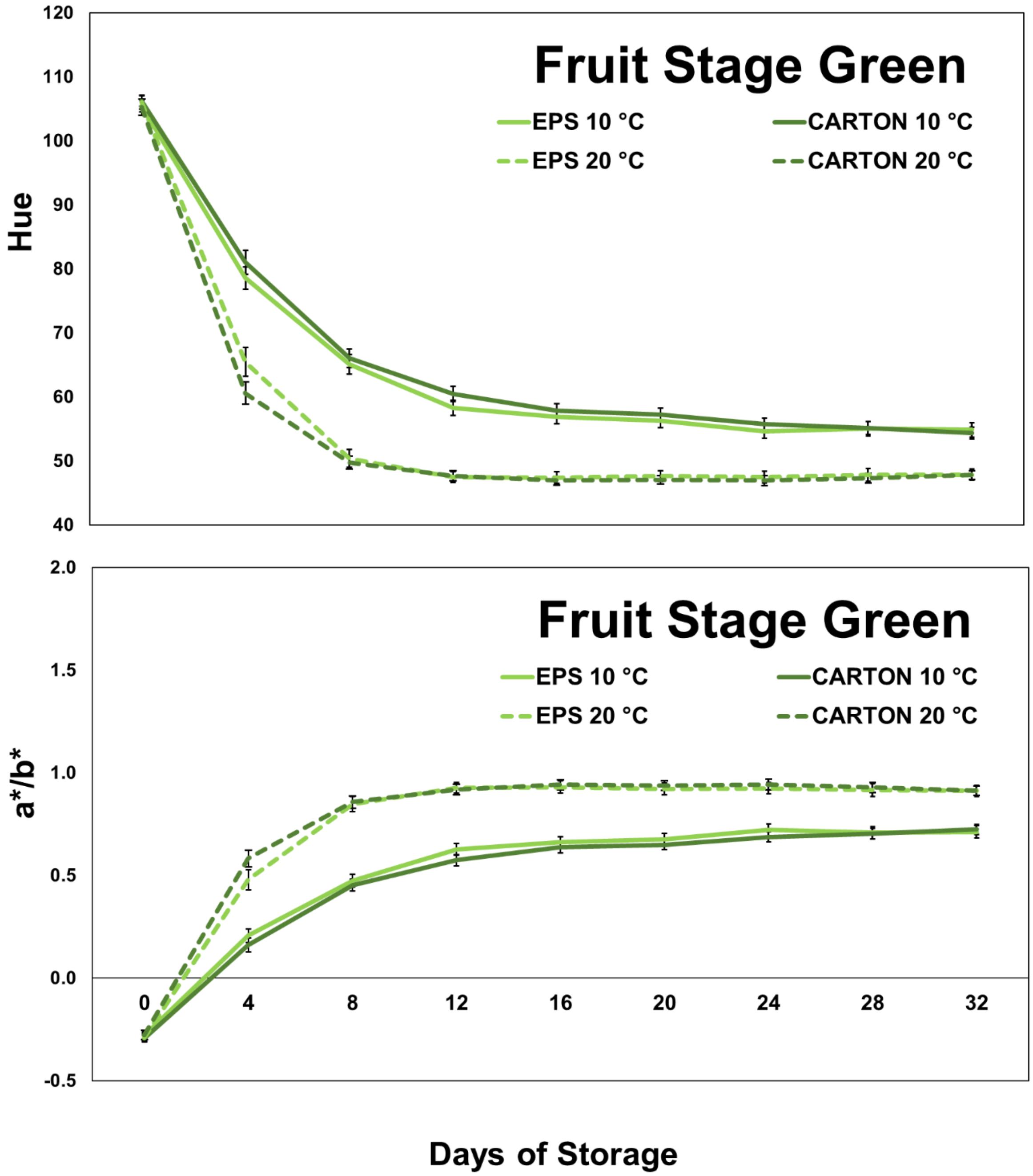


Figure 79. Hue angle and a/b (± S.E.) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

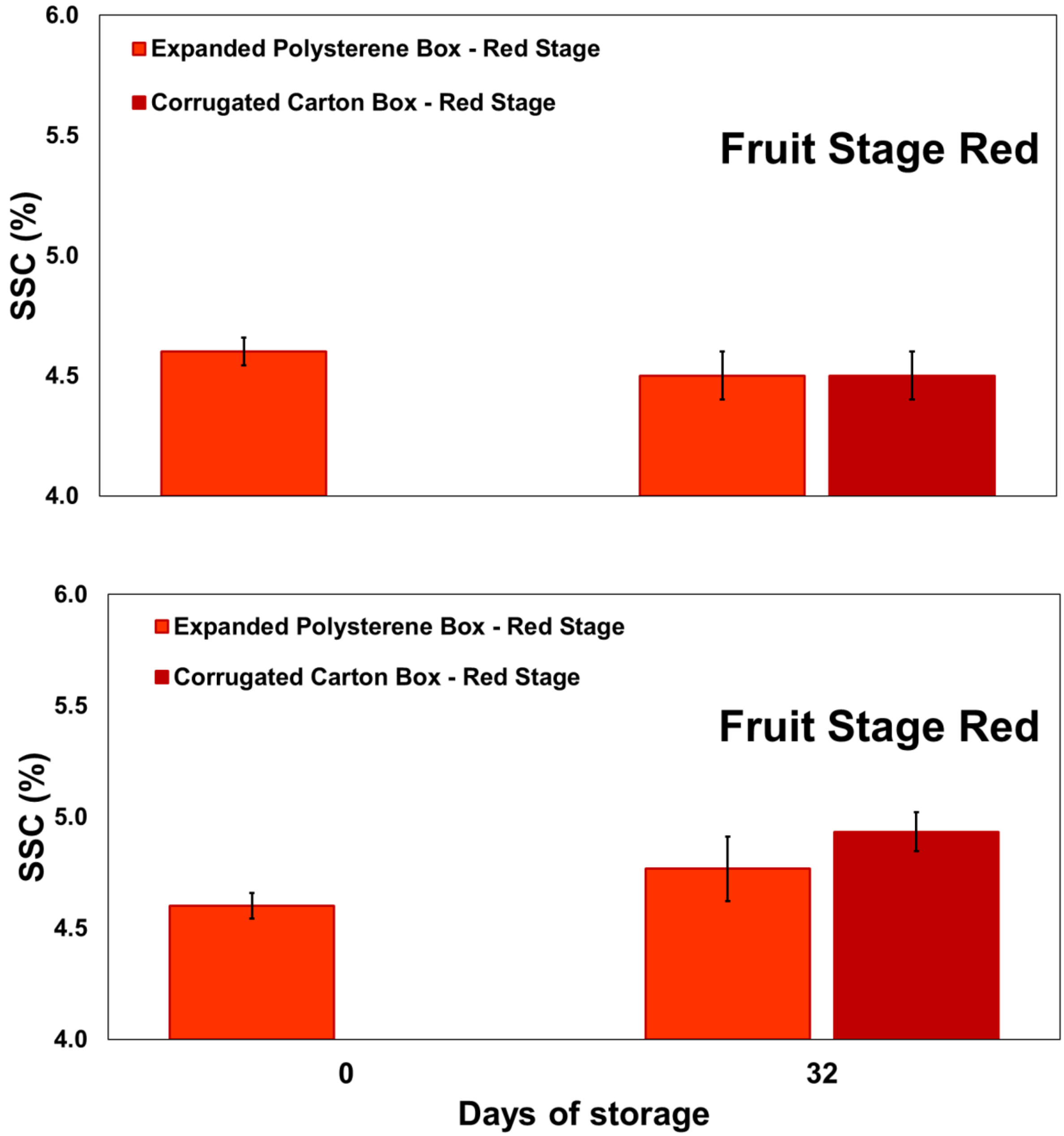


Figure 80. Soluble solids content (SSC) (%) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

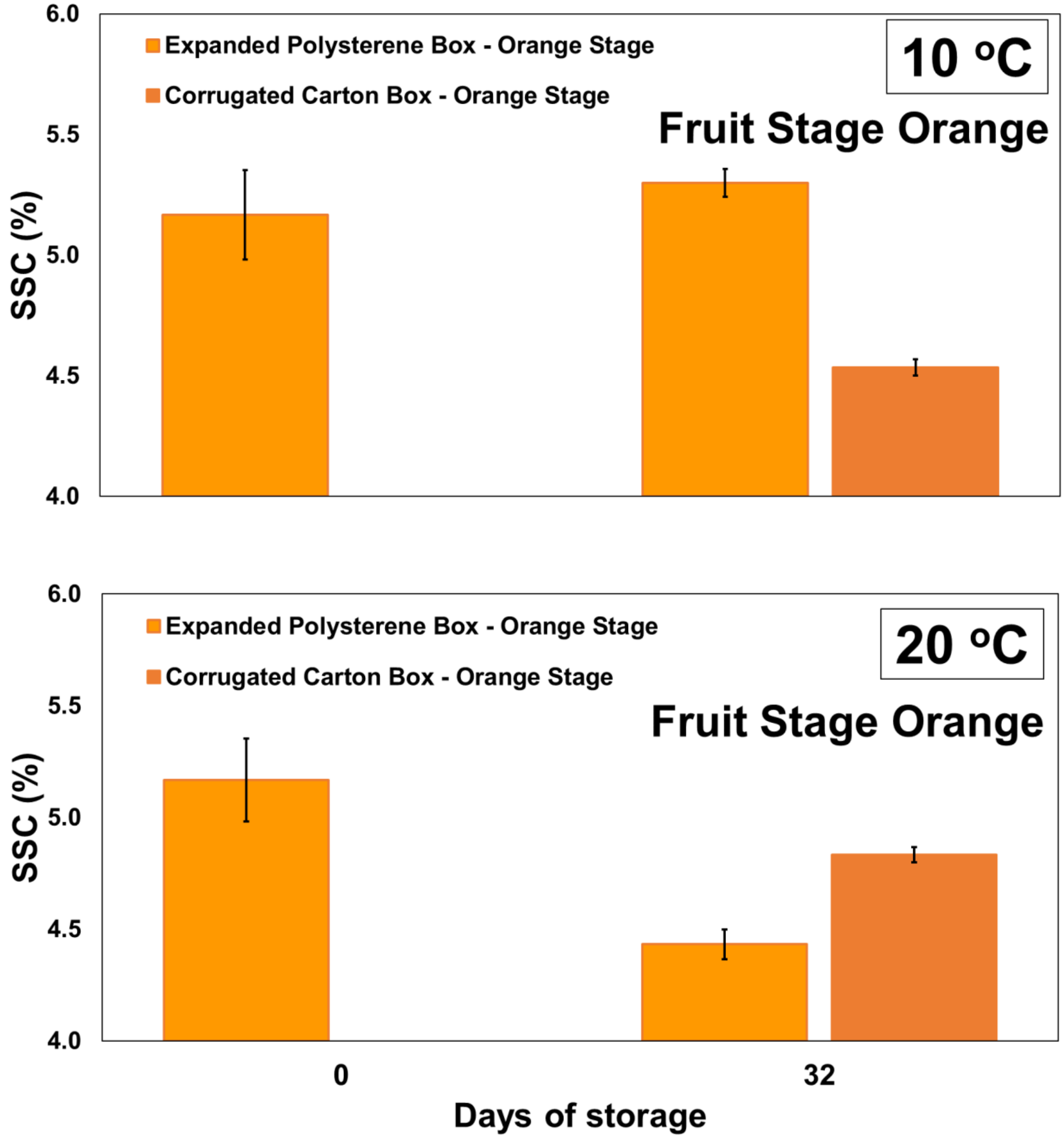


Figure 81. Soluble solids content (SSC) (%) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

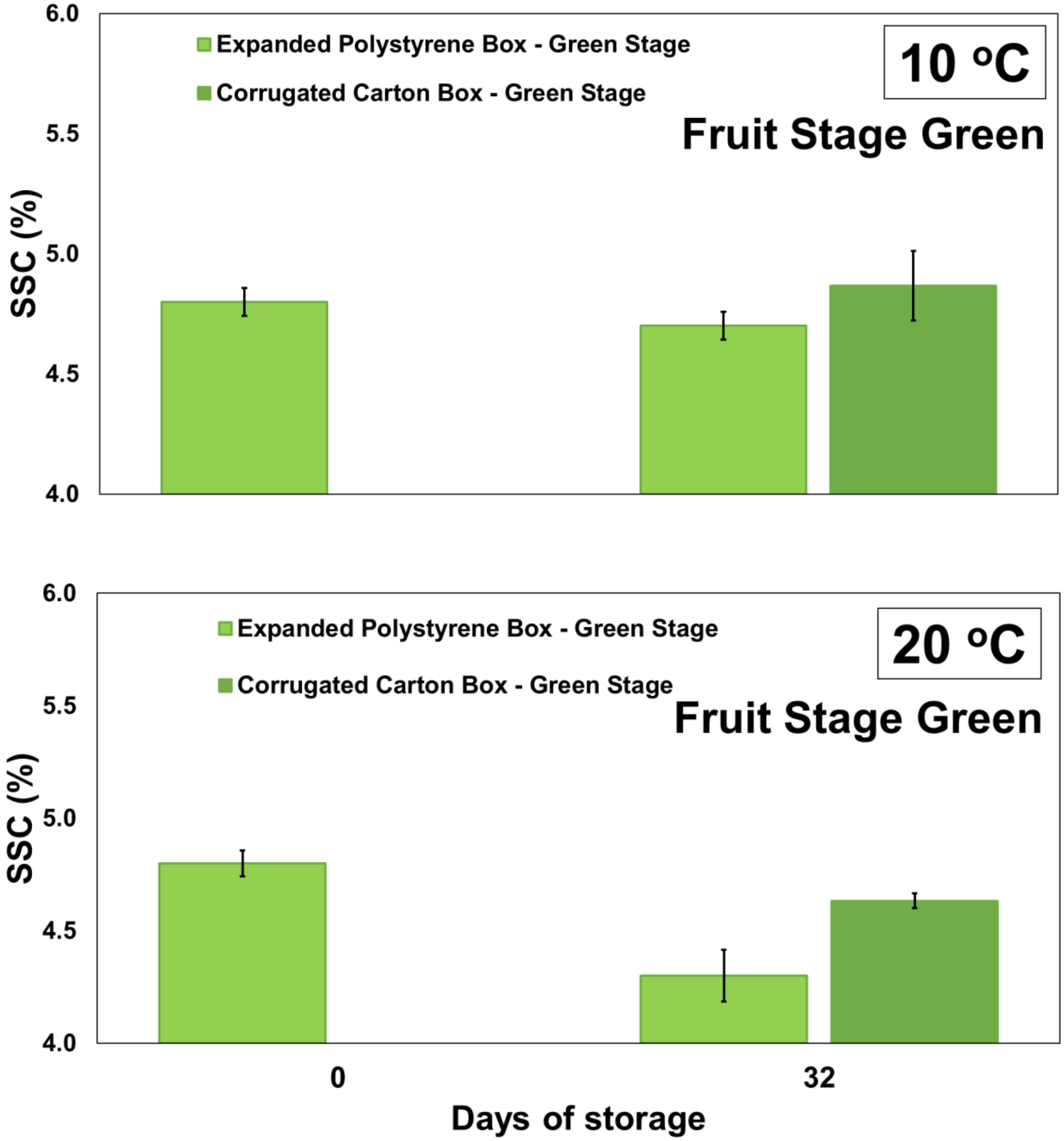


Figure 82. Soluble solids content (SSC) (%) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

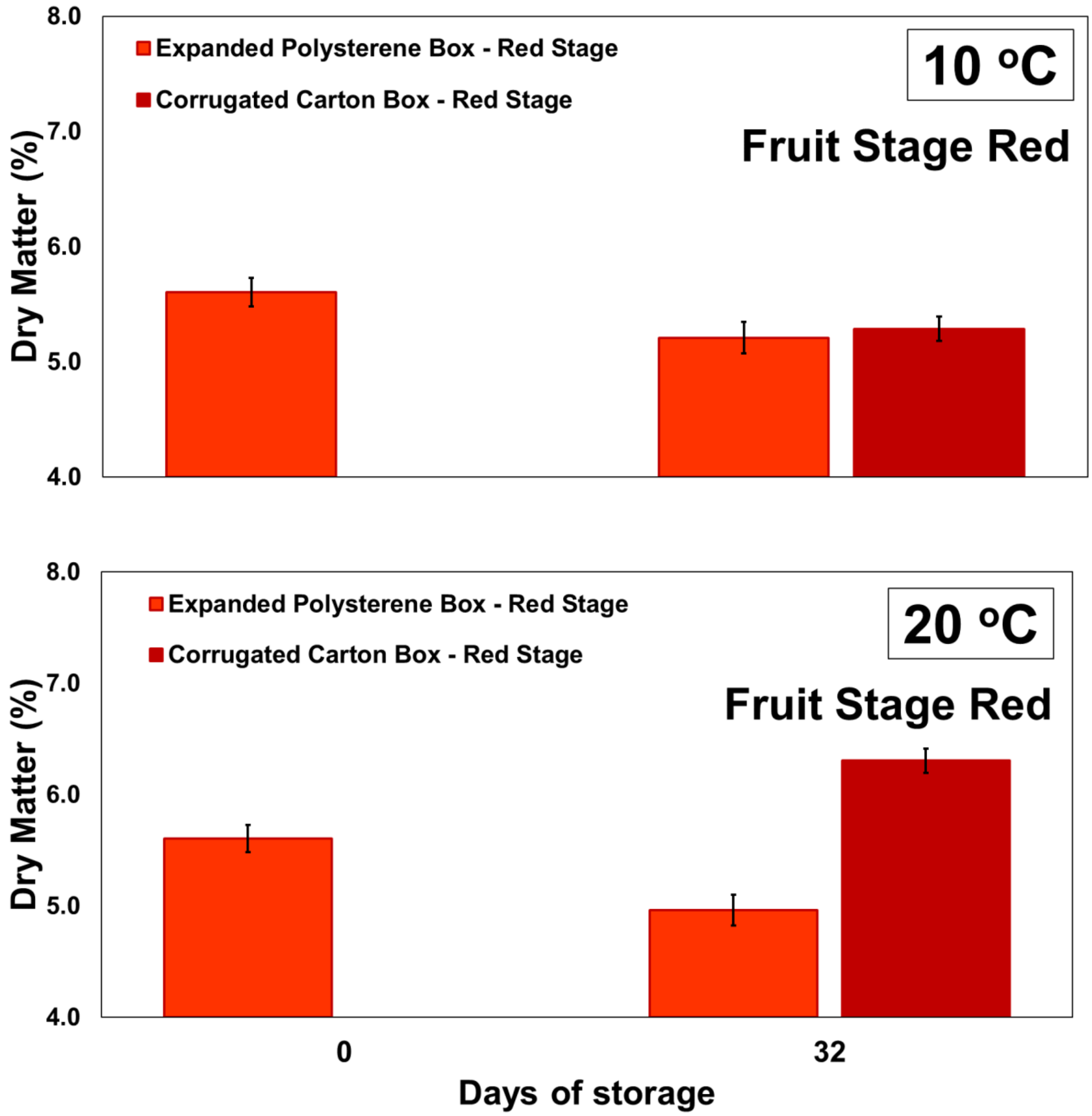


Figure 83. Dry matter content (%) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

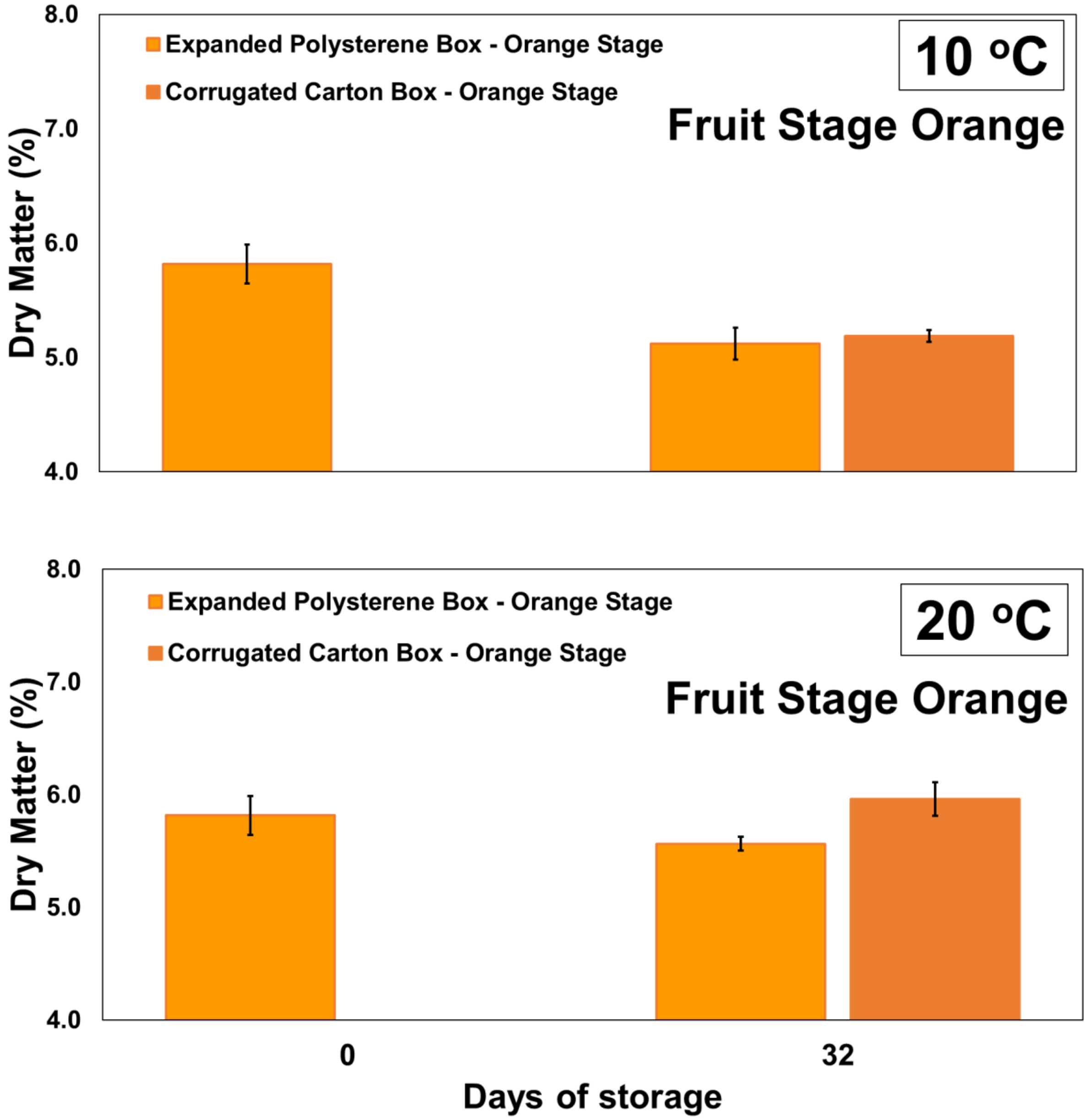


Figure 84. Dry matter content (%) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

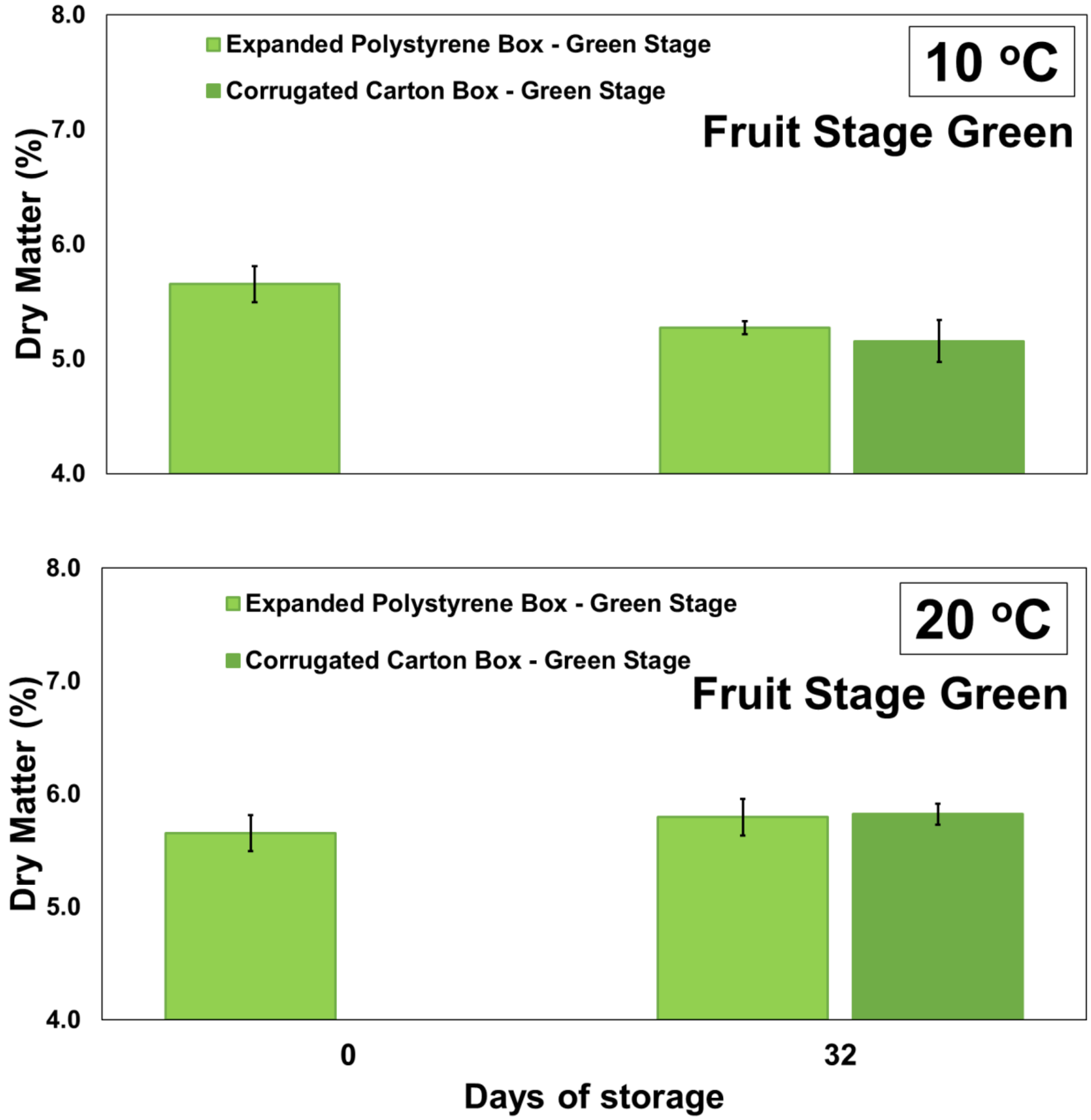


Figure 85. Dry matter content (%) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

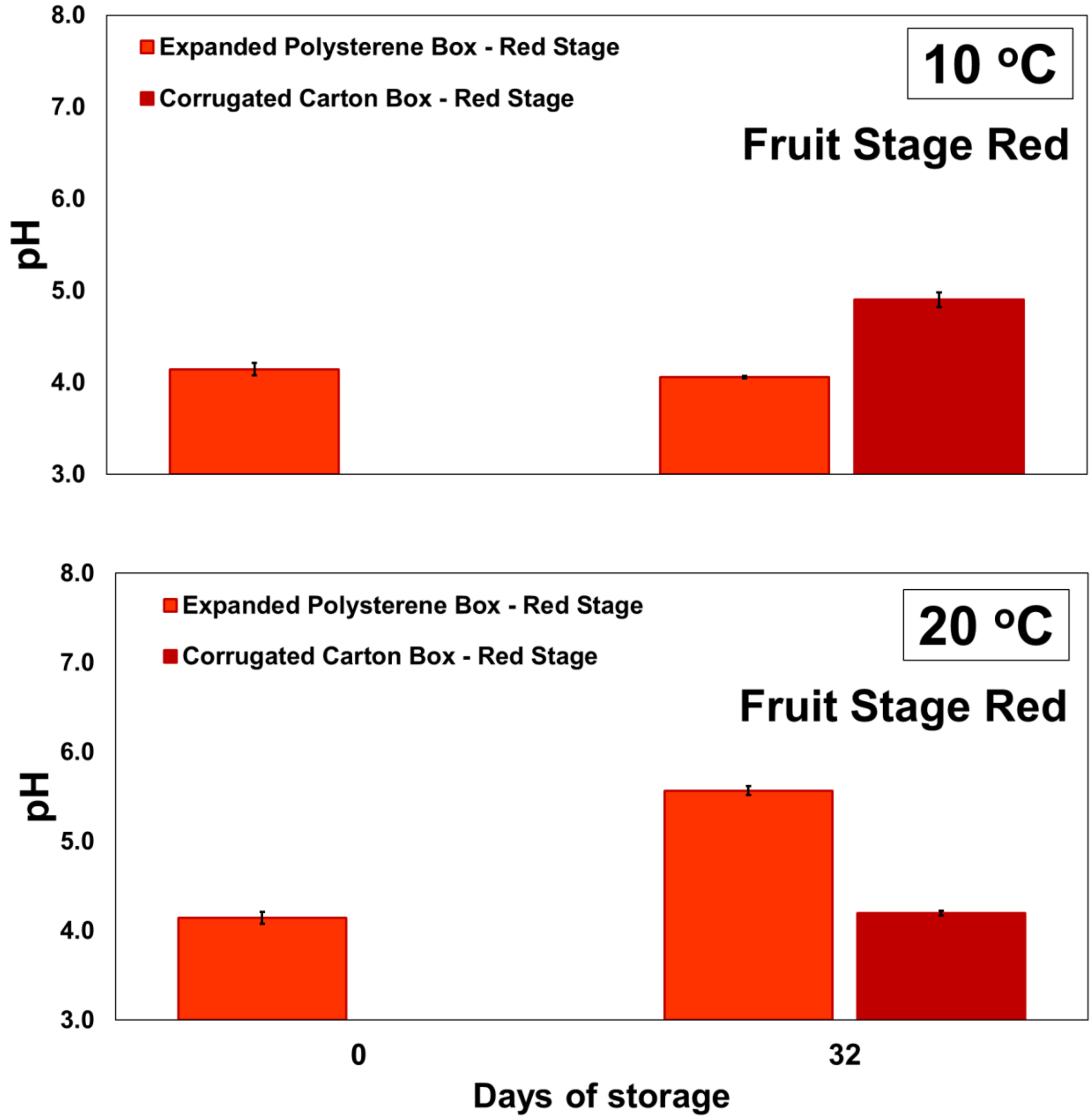


Figure 86. pH of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 32 days.

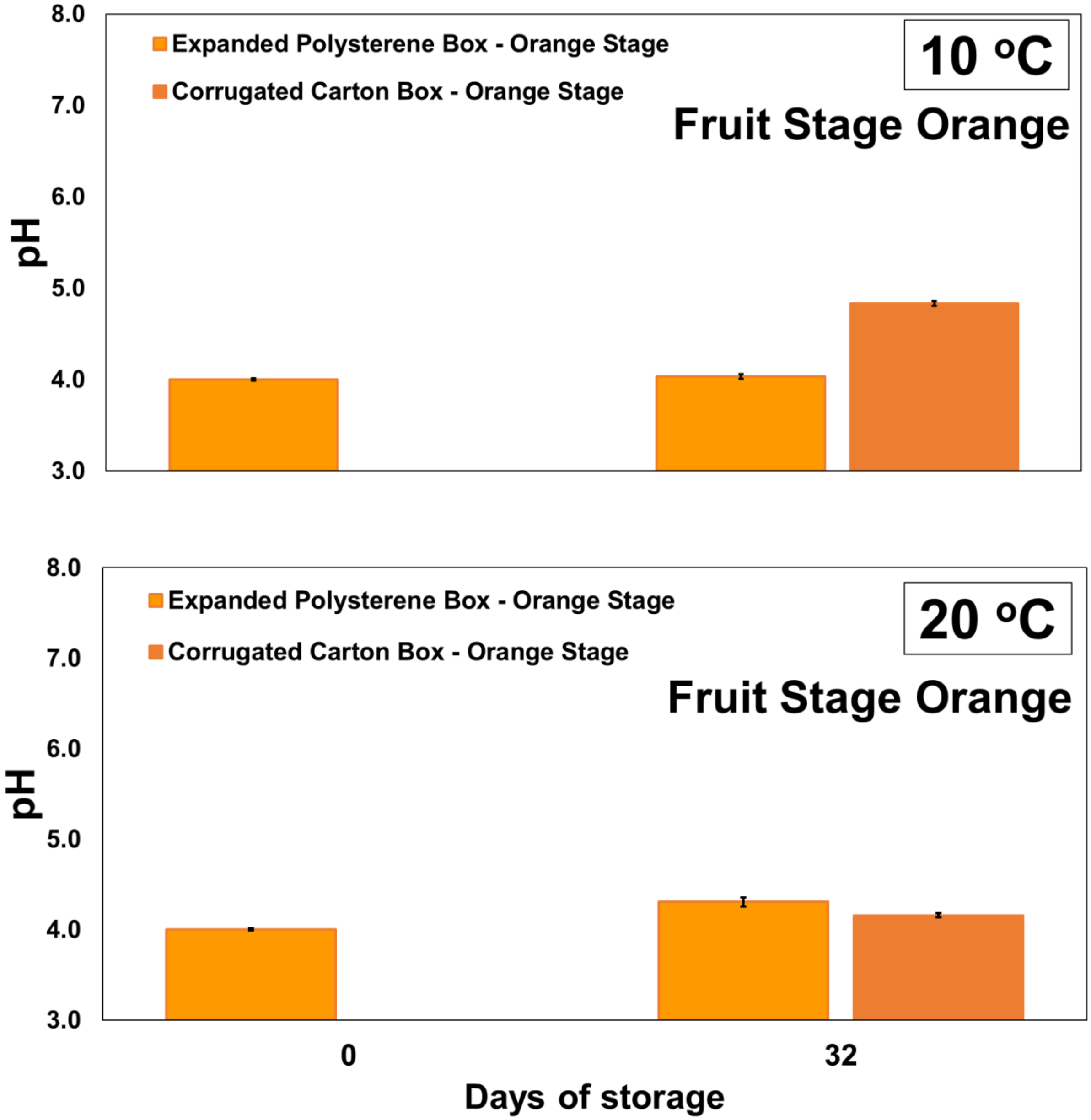


Figure 87. pH of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

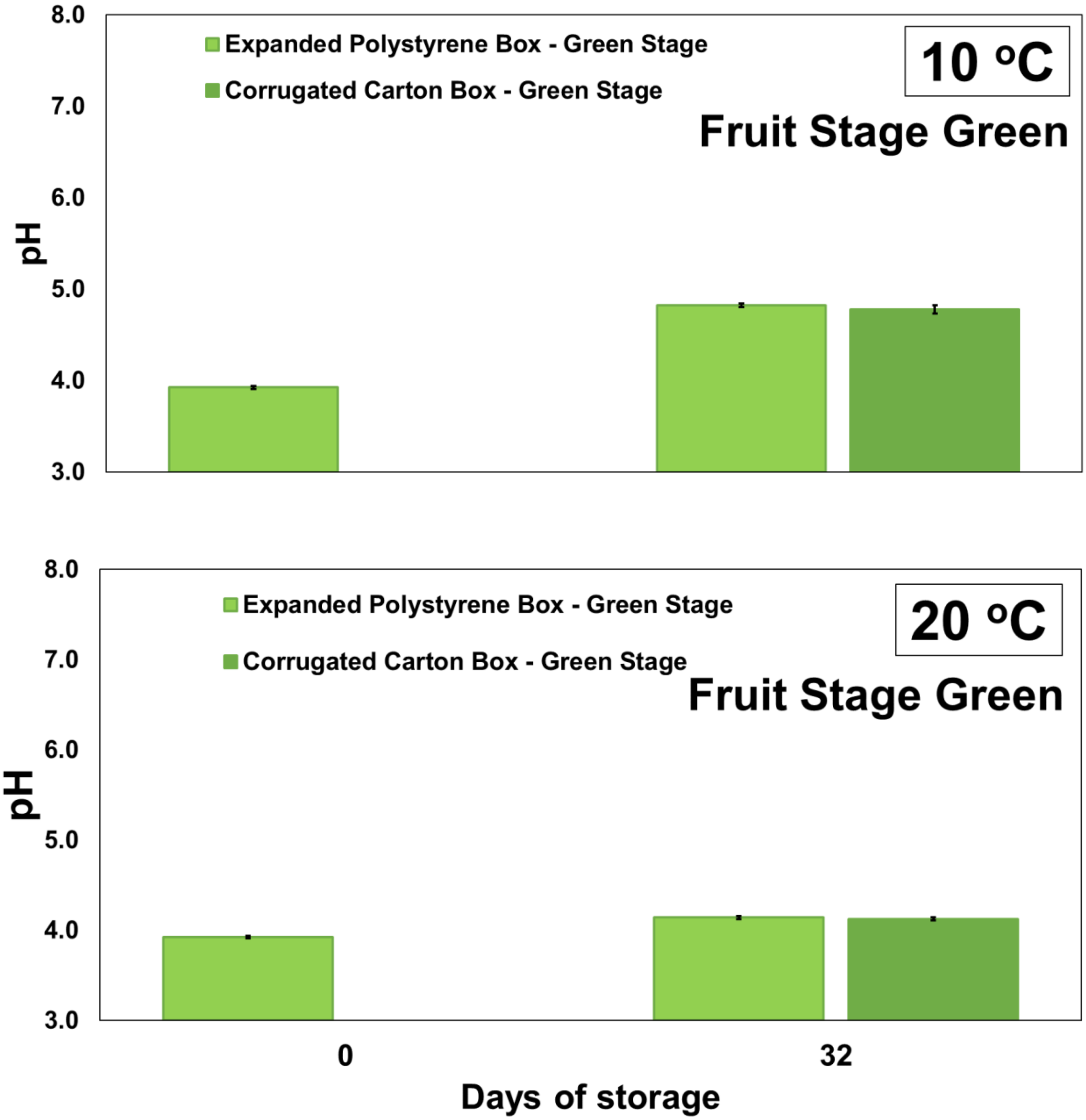


Figure 88. pH of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

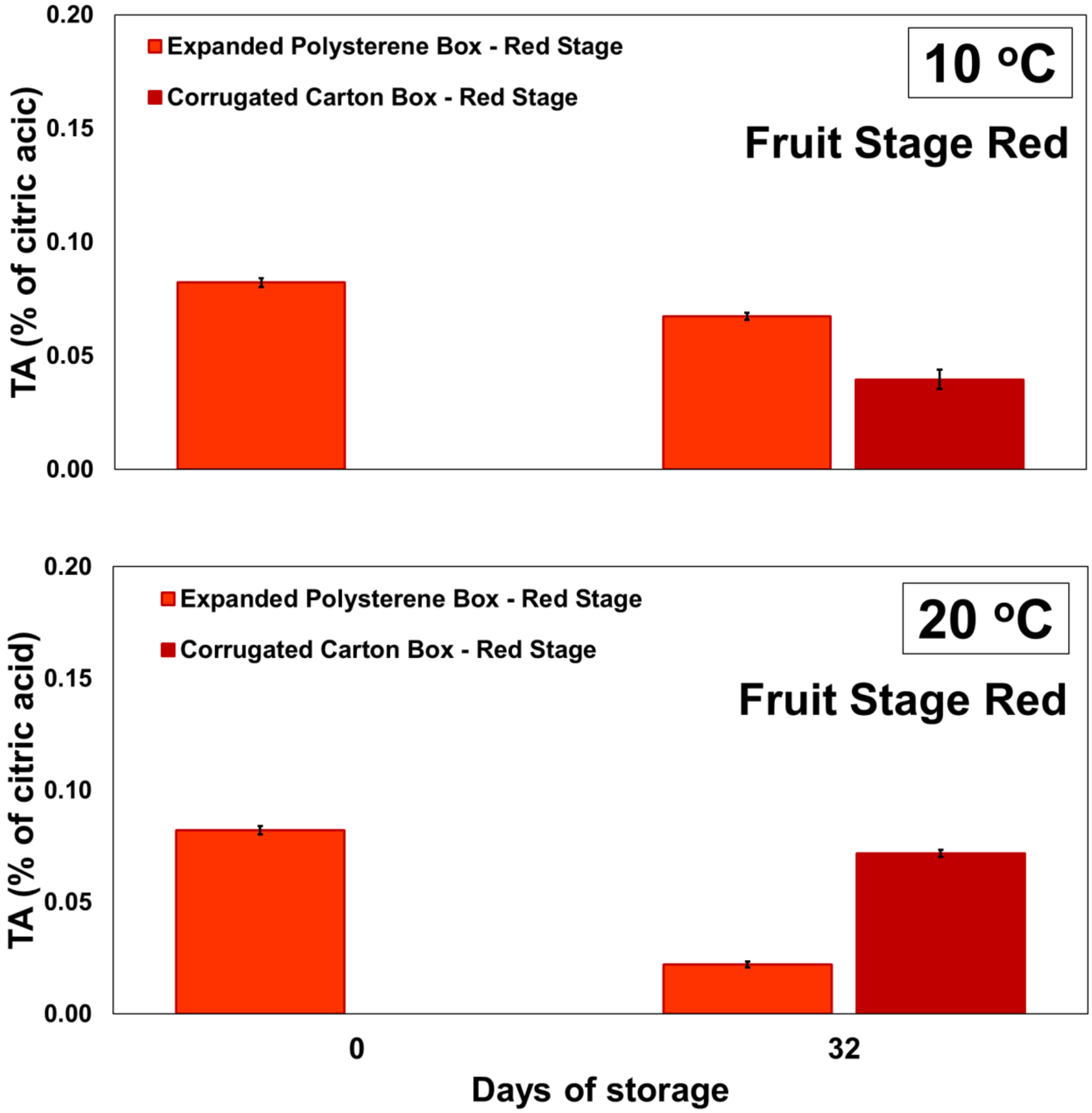


Figure 89. Titratable acidity (TA) (% citric acid) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

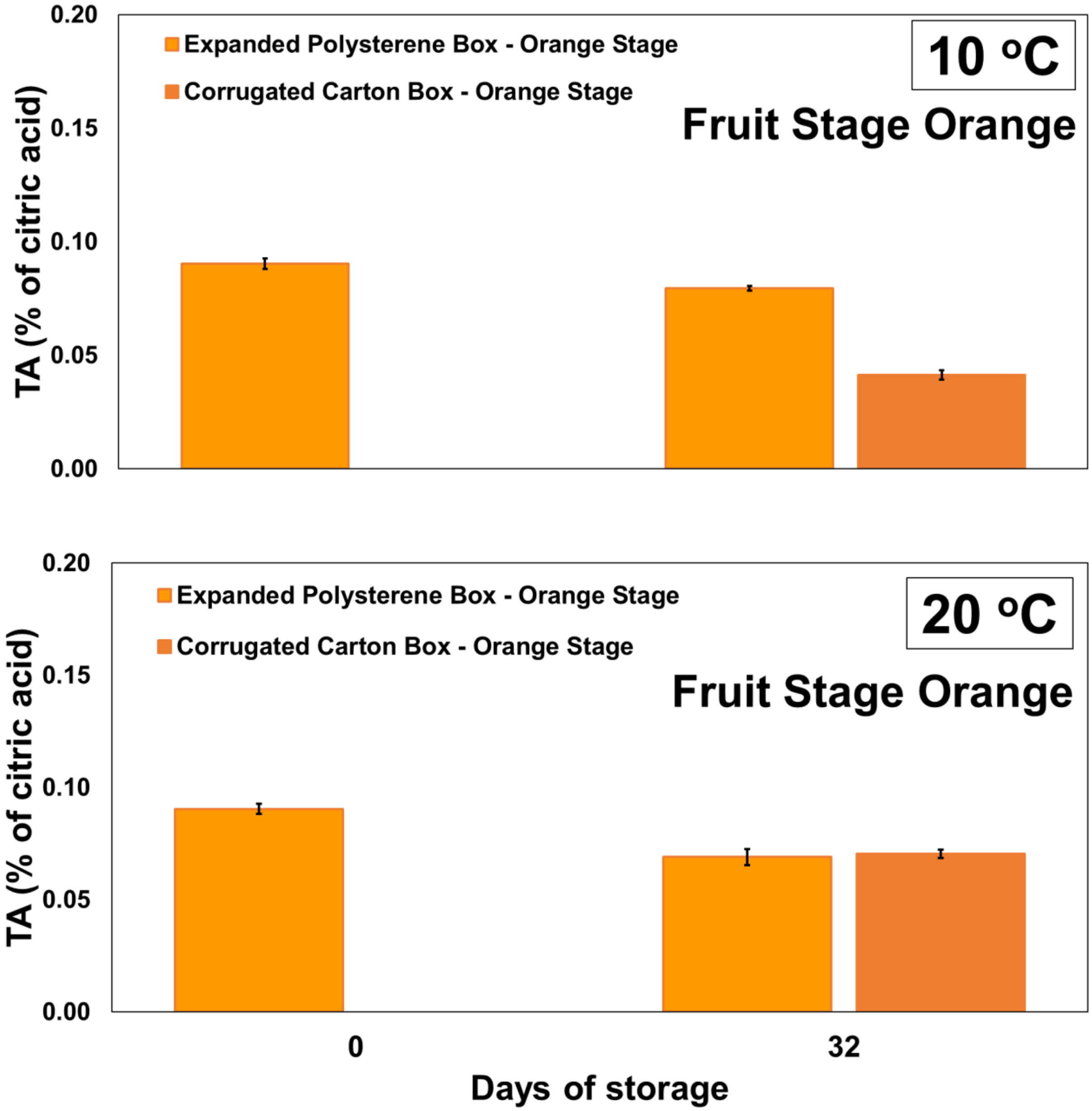


Figure 90. Titratable acidity (TA) (% citric acid) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 32 days.

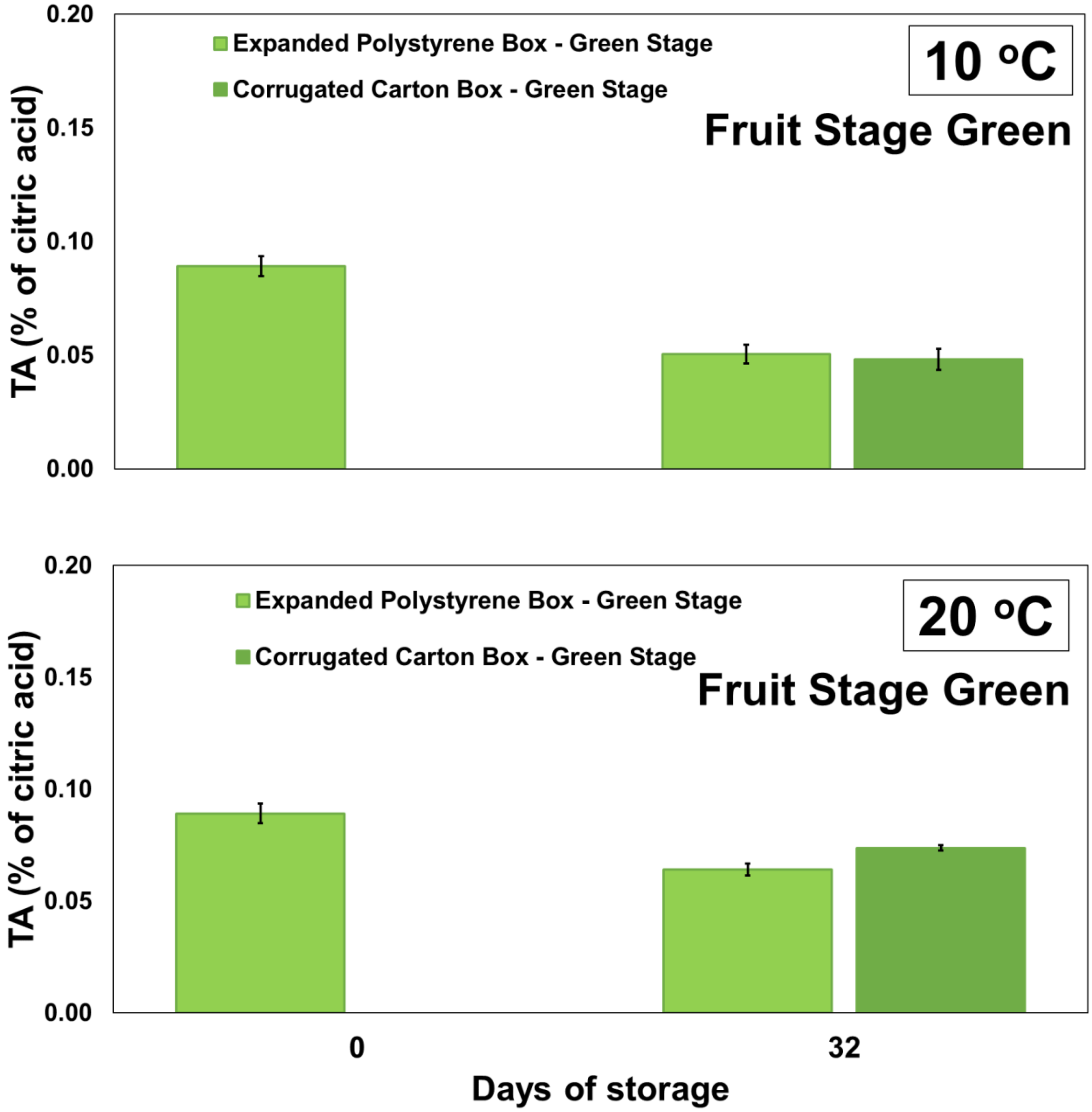


Figure 91. Titratable acidity (TA) (% citric acid) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 32 days.

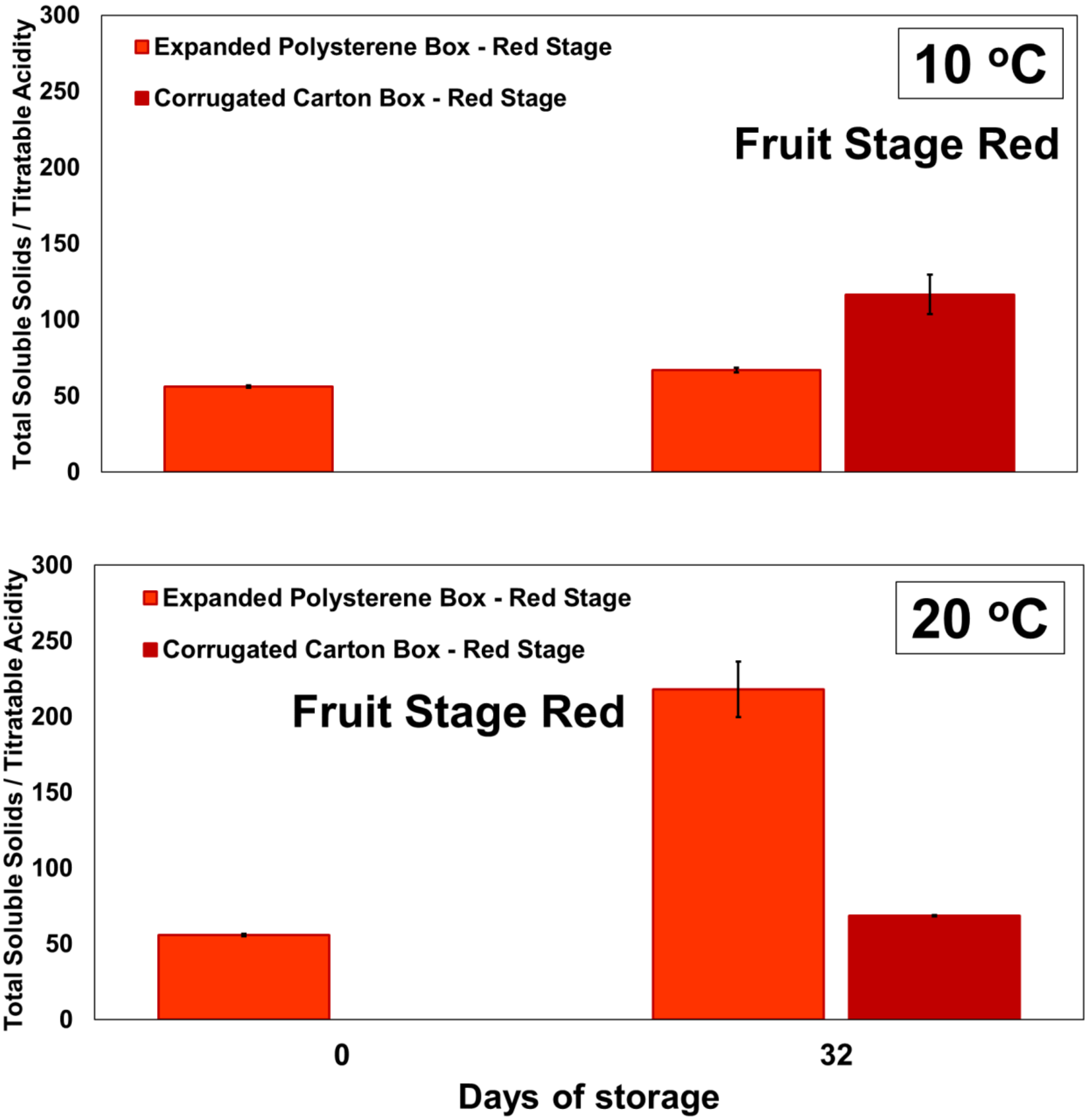


Figure 92. Total soluble solids content/ titratable acidity ratio of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

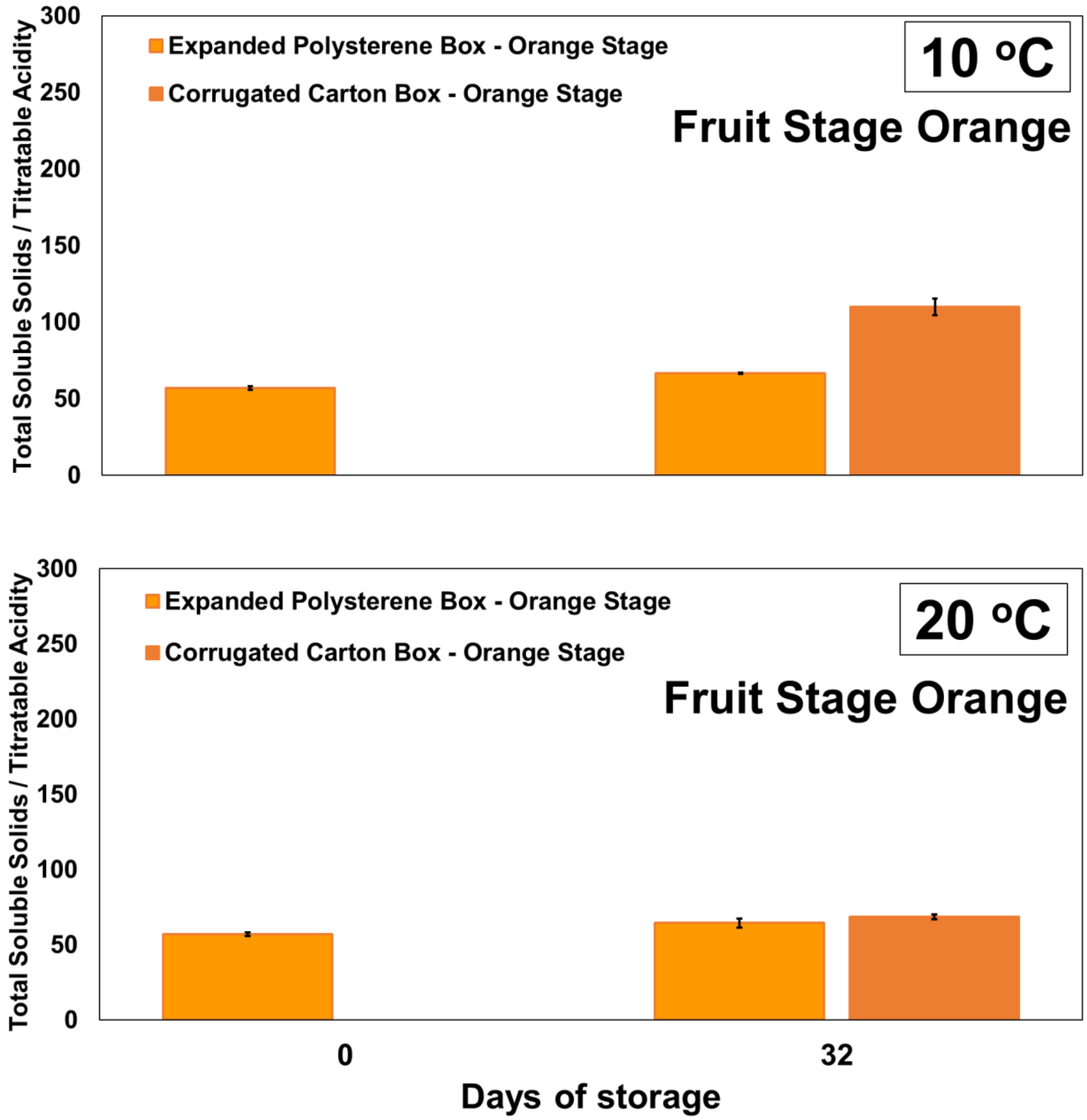


Figure 93. Total soluble solids content/ titratable acidity ratio of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

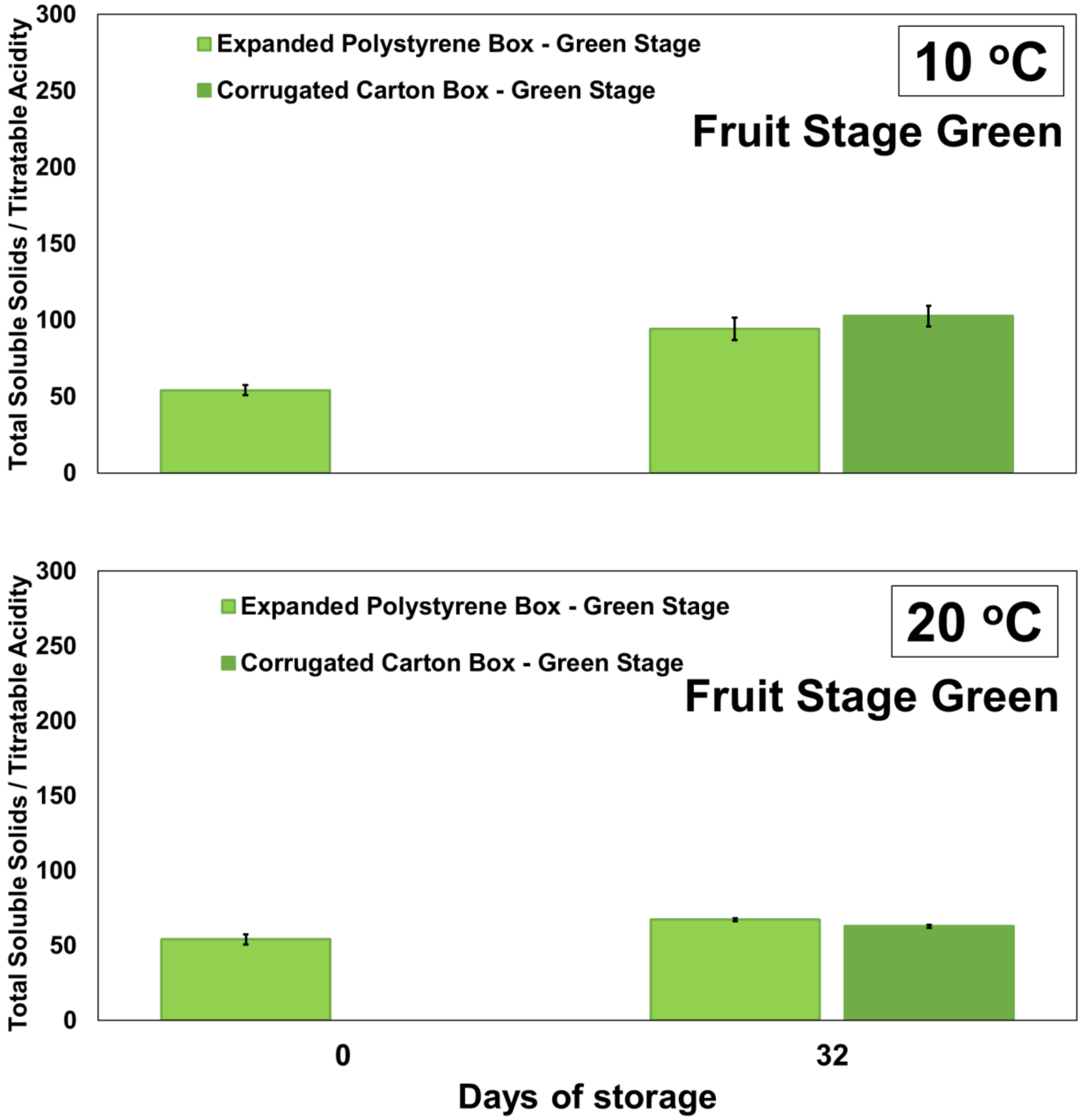


Figure 94. Total soluble solids content/ titratable acidity ratio of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

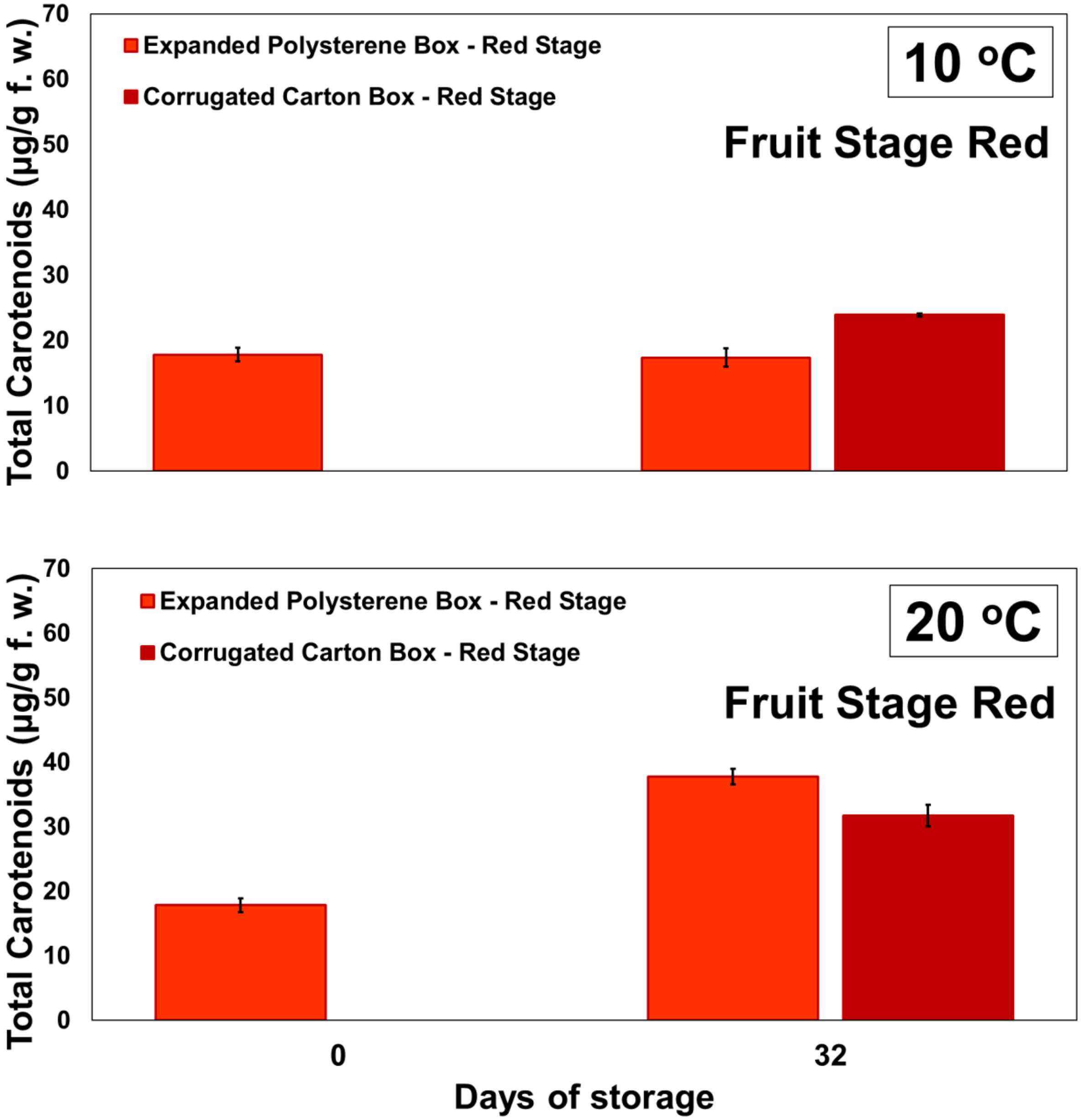


Figure 95. Total carotenoid content (µg/g f.w.) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

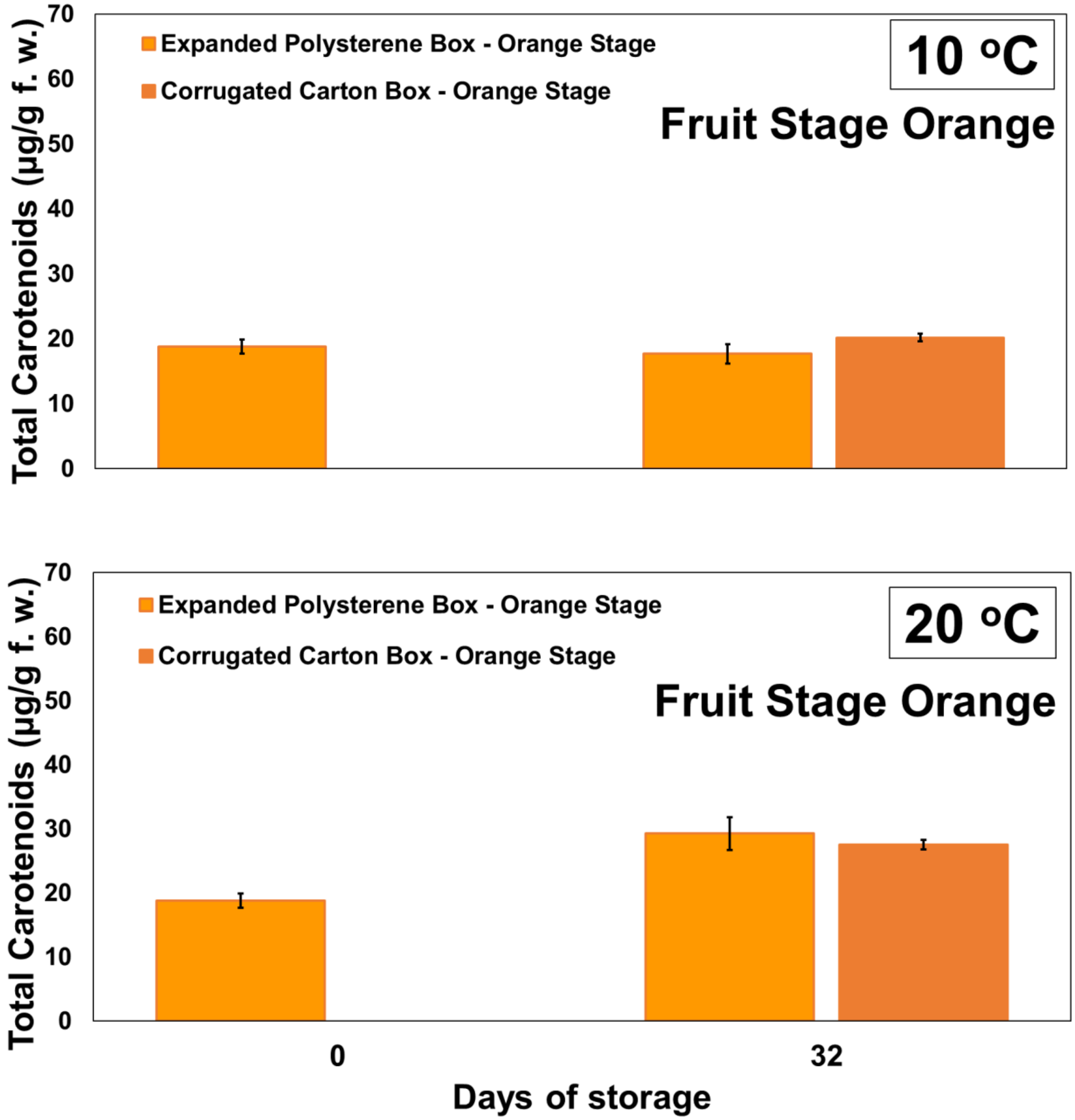


Figure 96. Total carotenoid content (µg/g f.w.) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 32 days.

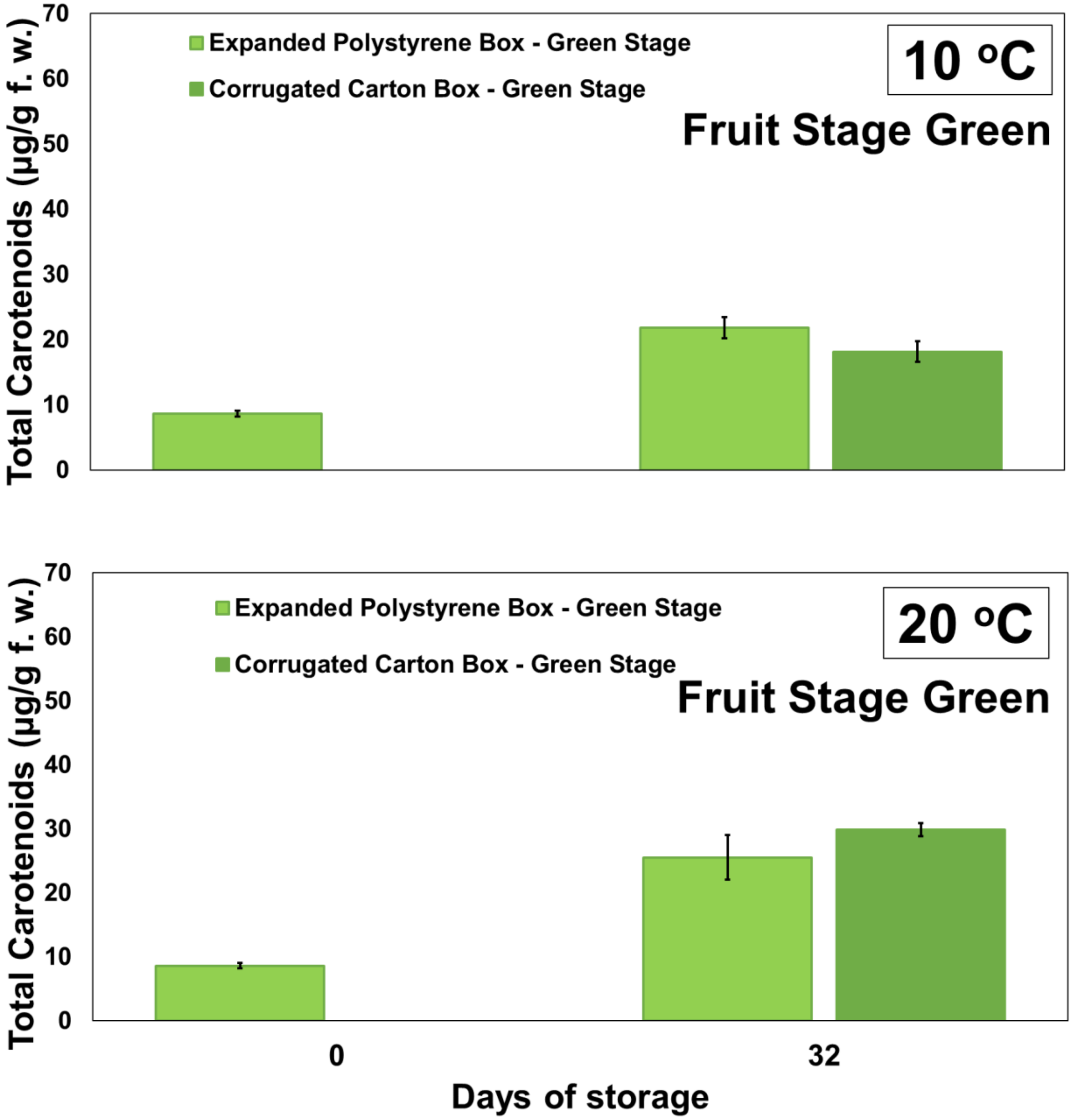


Figure 97. Total carotenoid content (µg/g f.w.) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

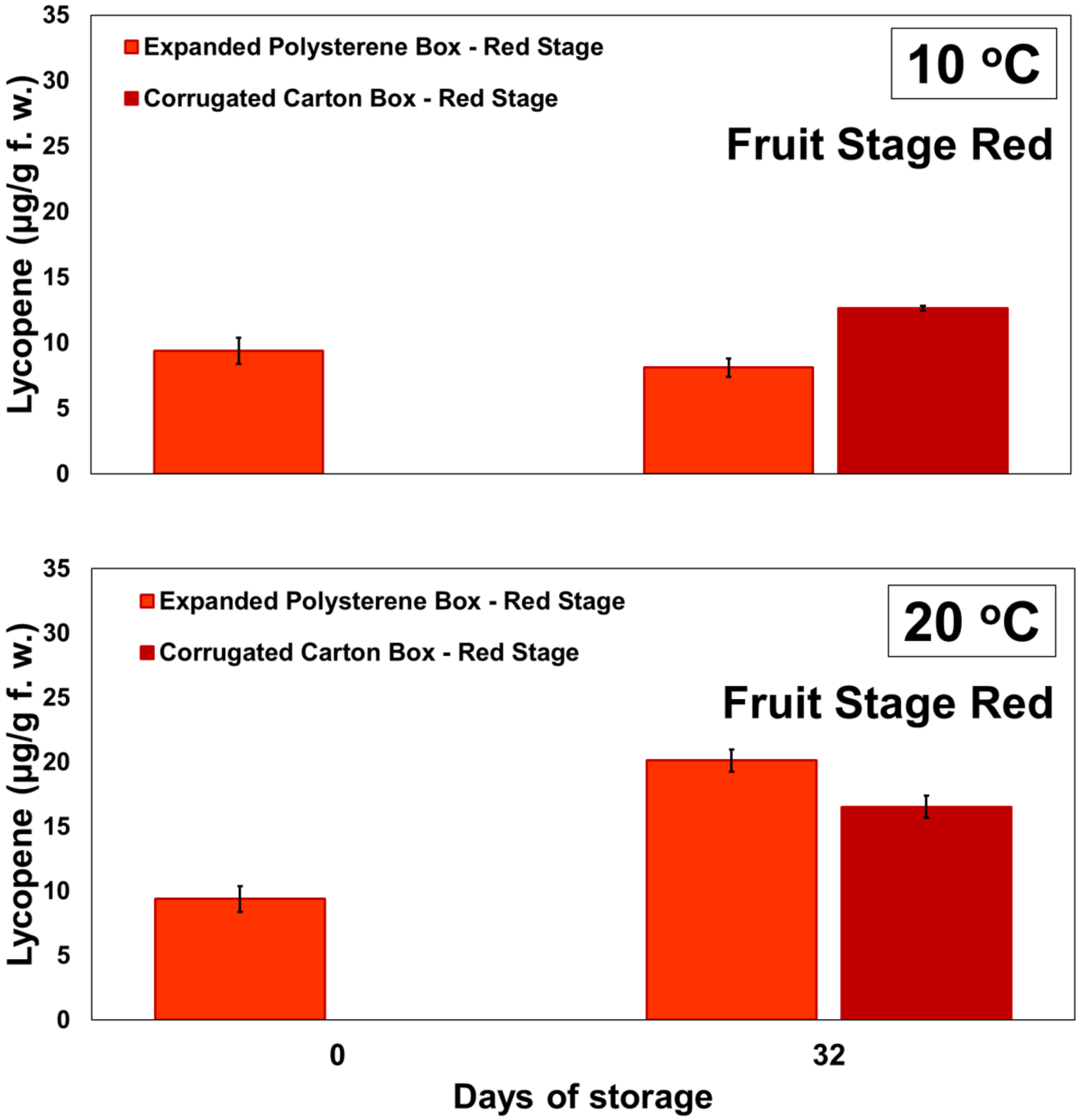


Figure 98. Lycopene content (µg/g f.w.) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 32 days.

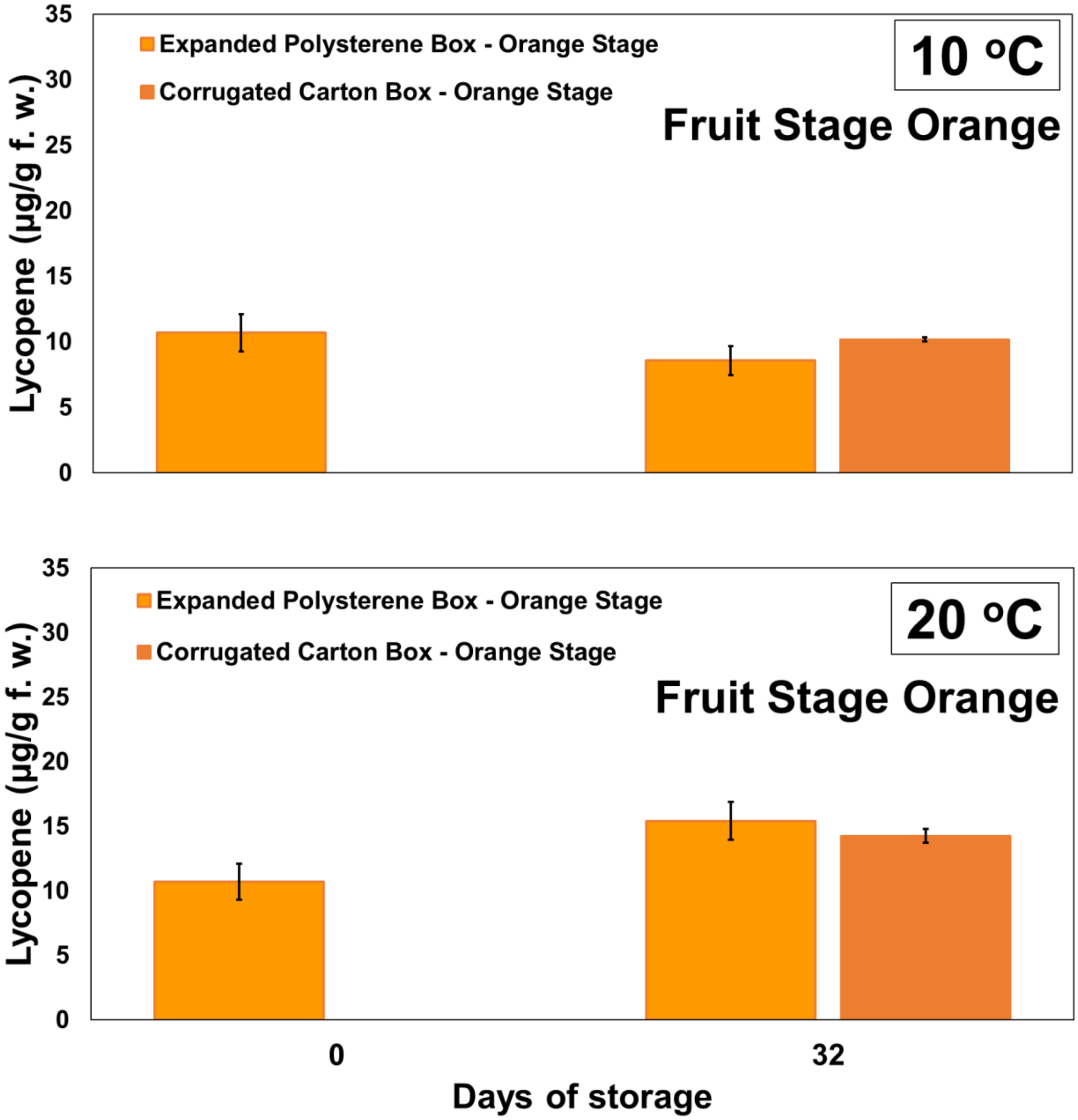


Figure 99. Lycopene content (µg/g f.w.) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

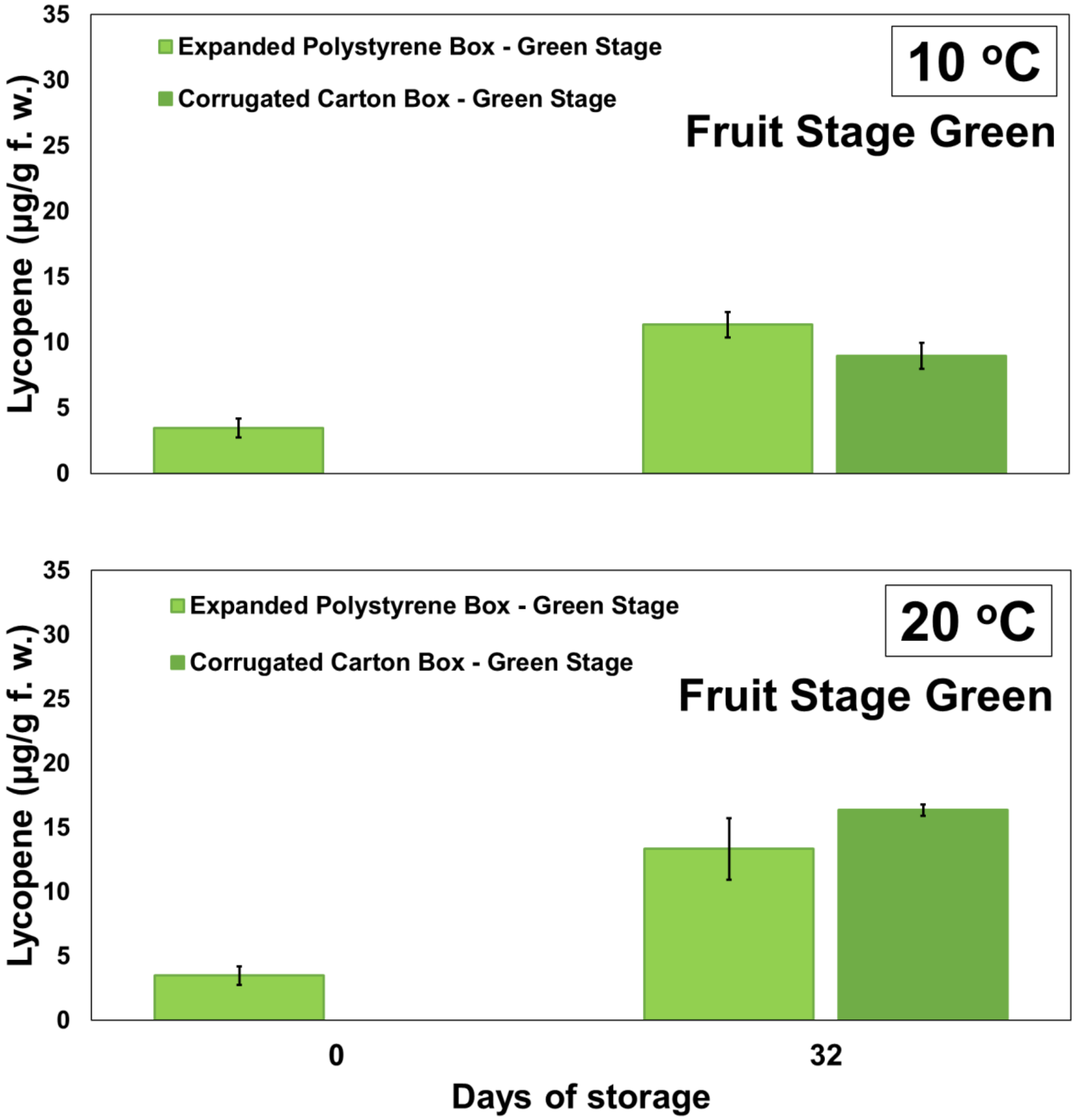


Figure 100. Lycopene content (μg/g f.w.) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

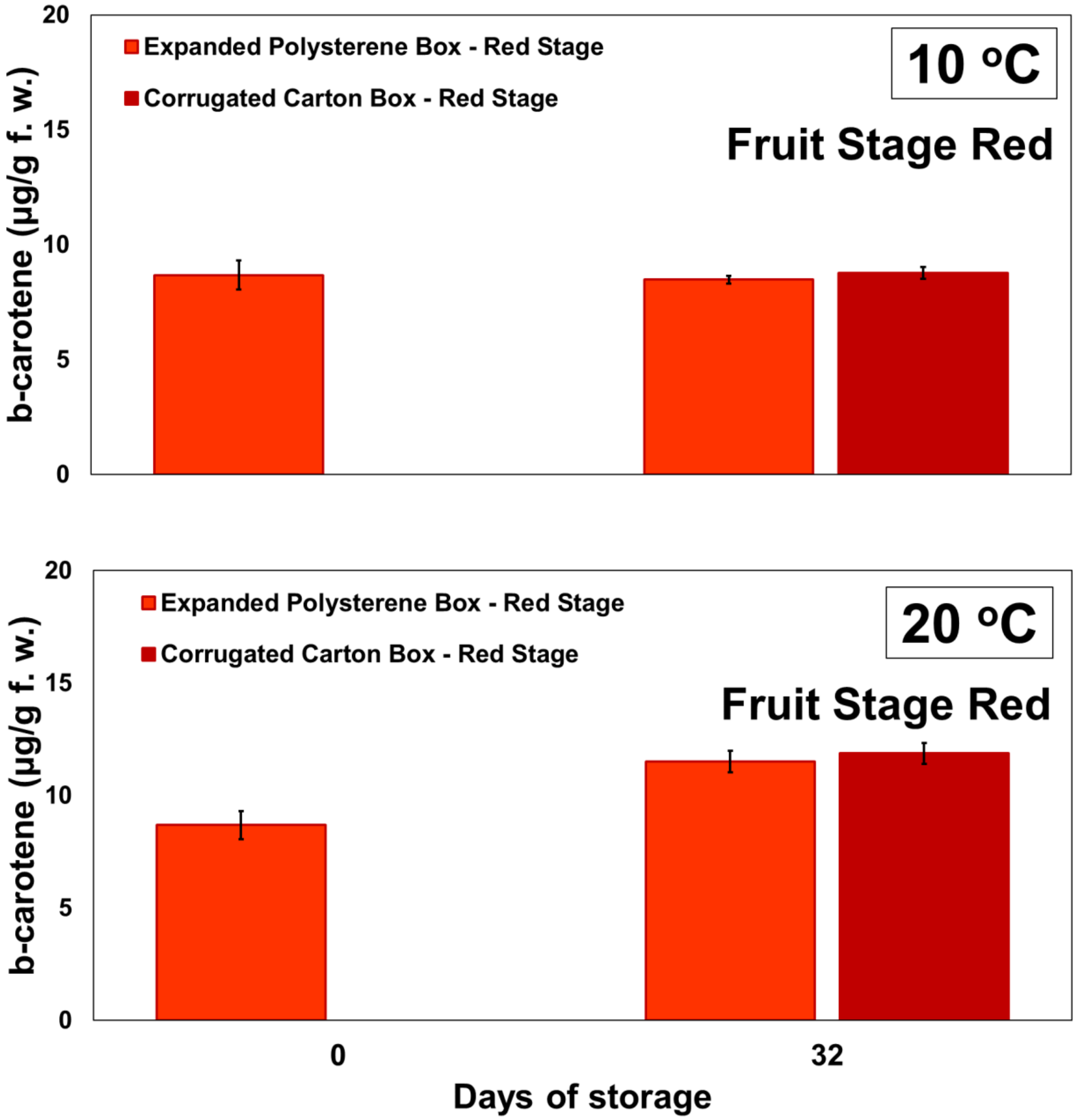


Figure 101. b-Carotene content (μg/g f.w.) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

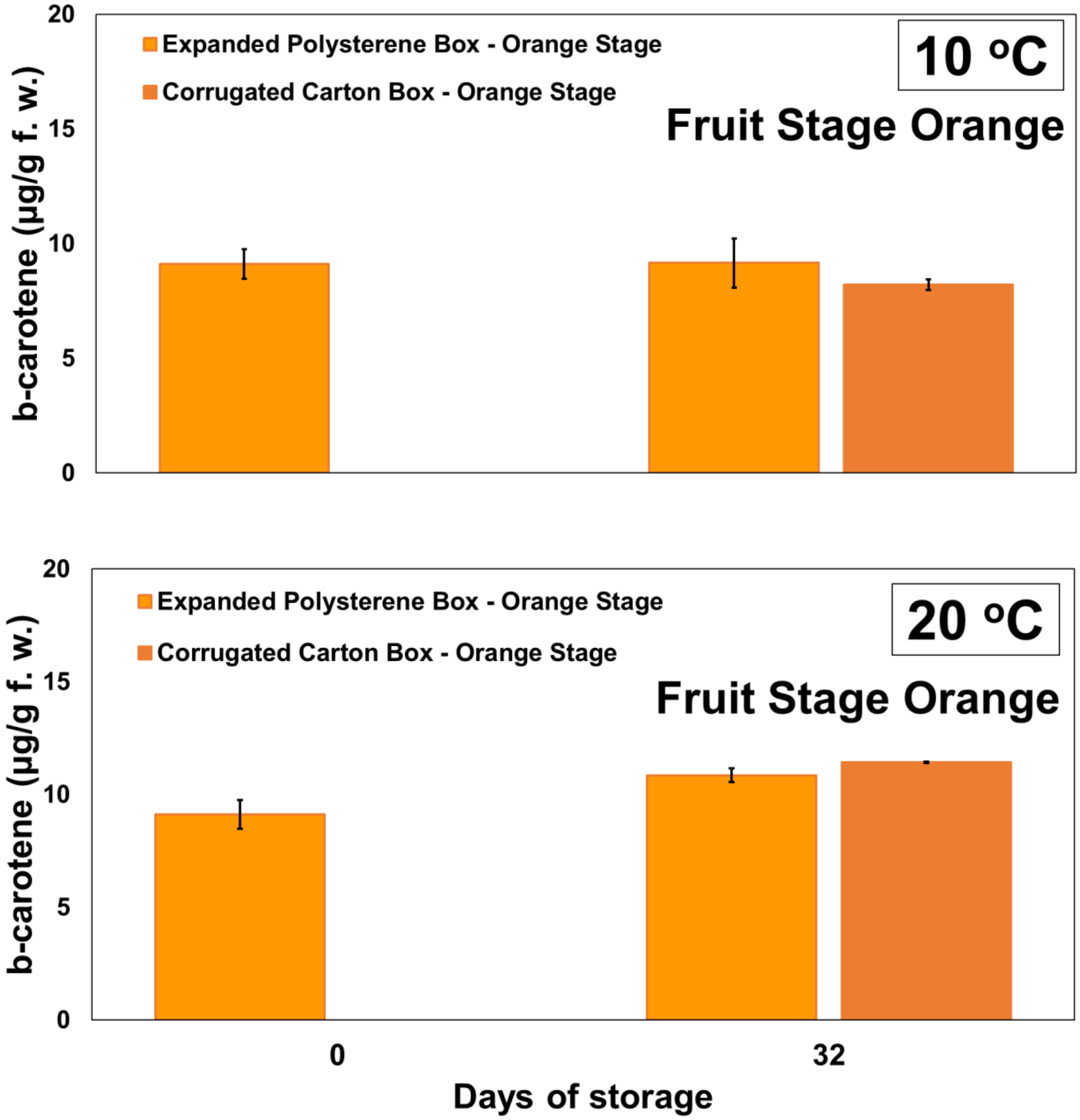


Figure 102. b-Carotene content (µg/g f.w.) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

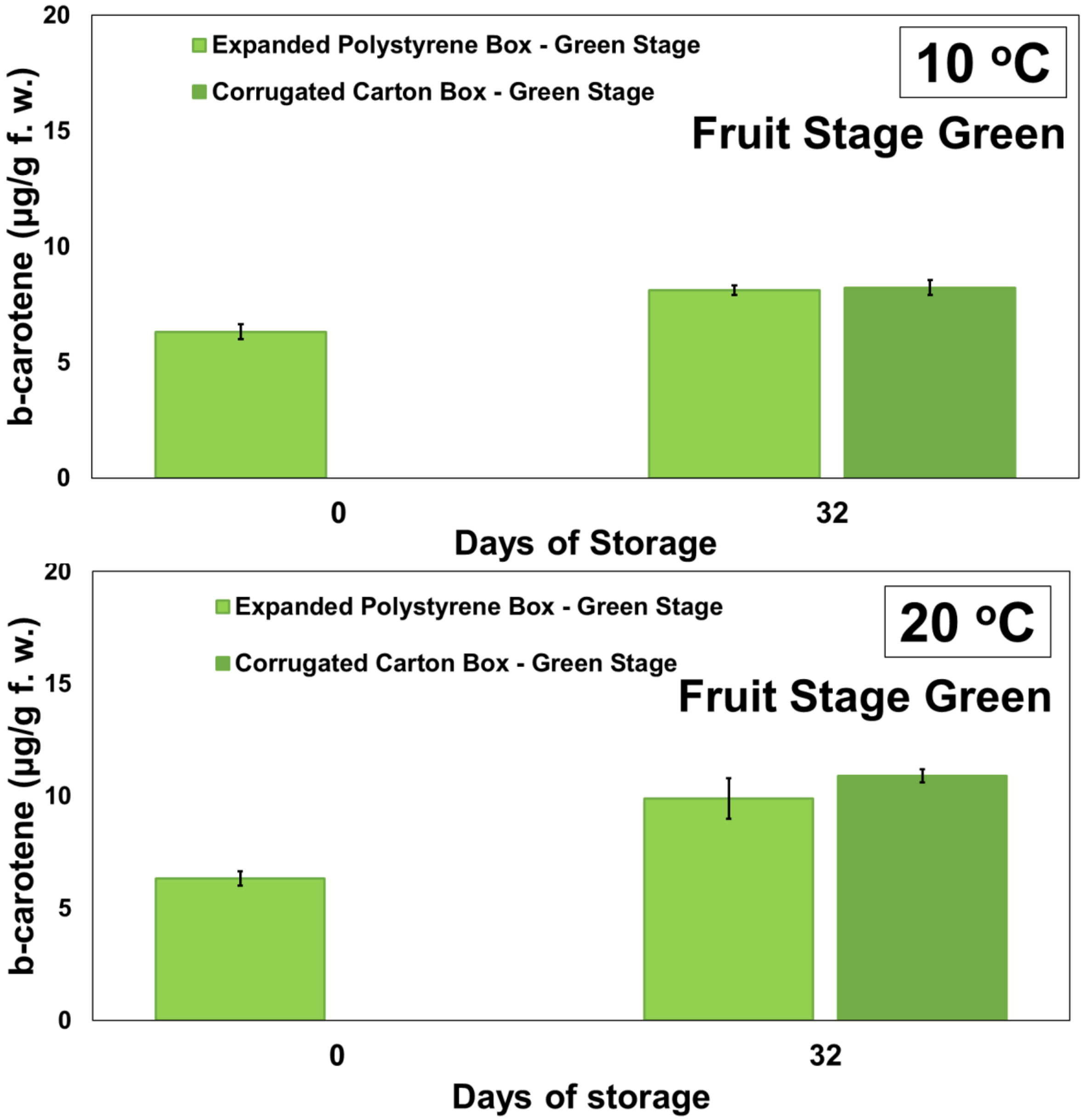


Figure 103. b-Carotene content (µg/g f.w.) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

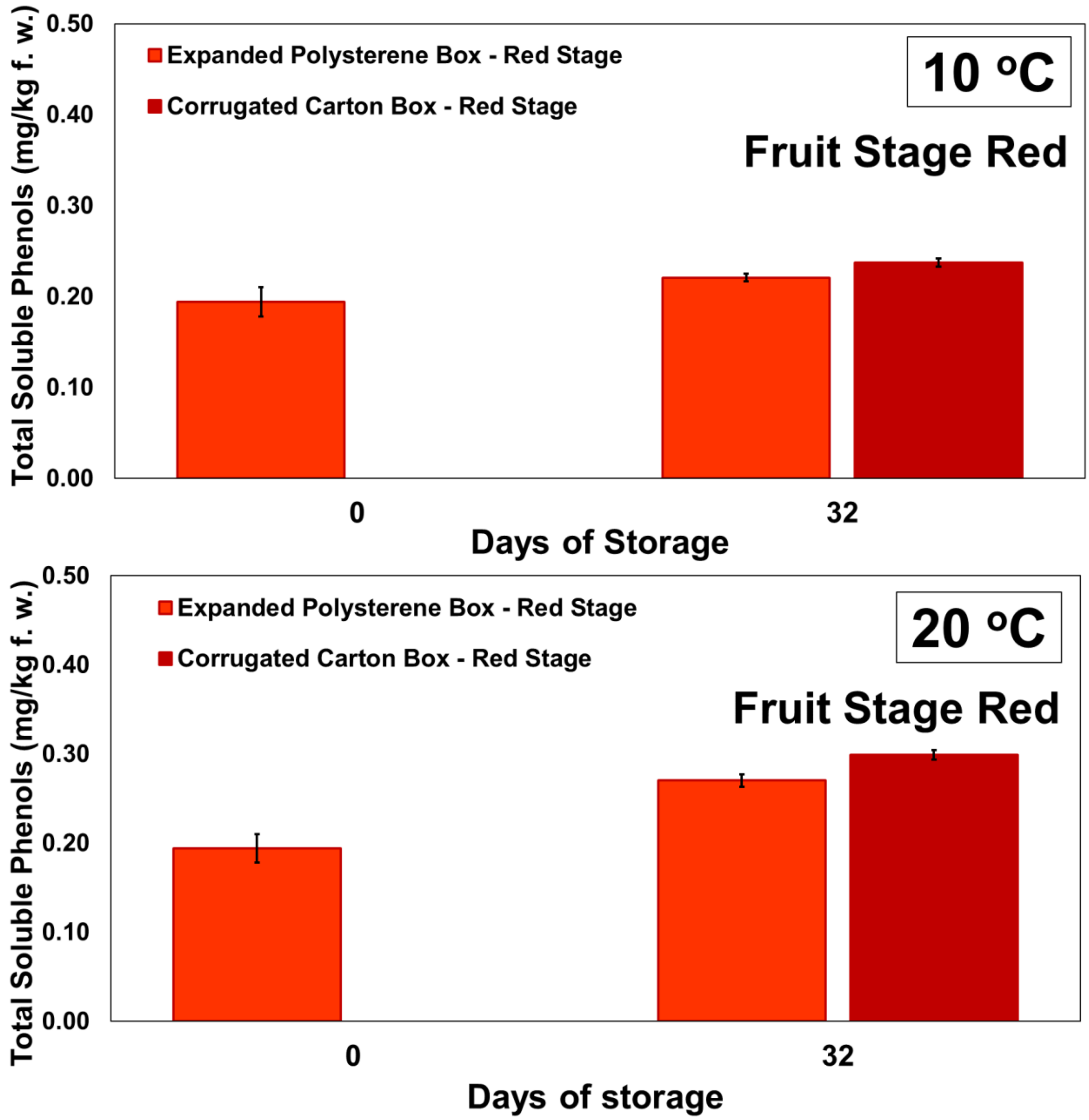


Figure 104. Total soluble phenols content (mg gallic acid equivalents/kg f.w.) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

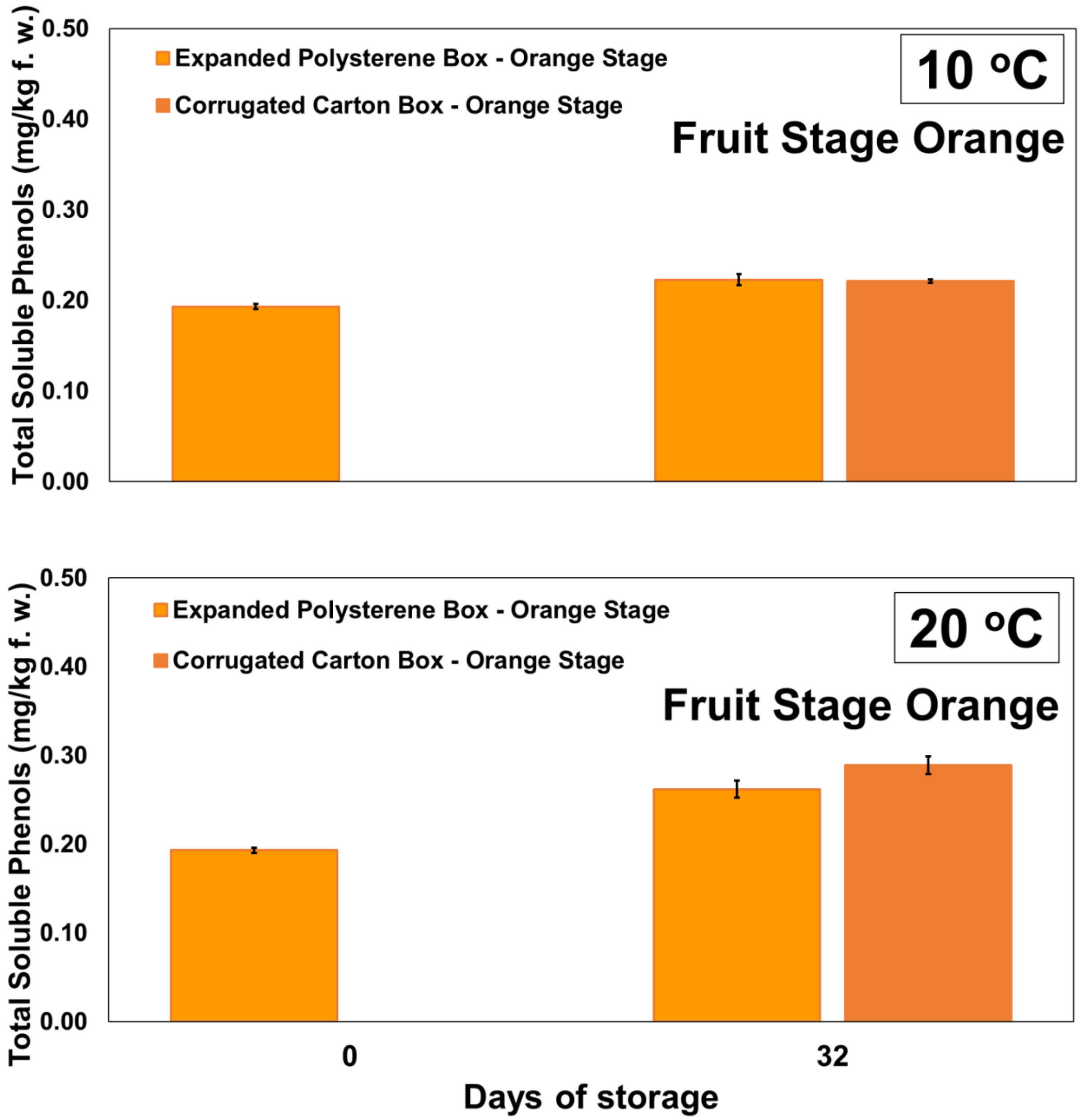


Figure 105. Total soluble phenols content (mg gallic acid equivalents/kg f.w.) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

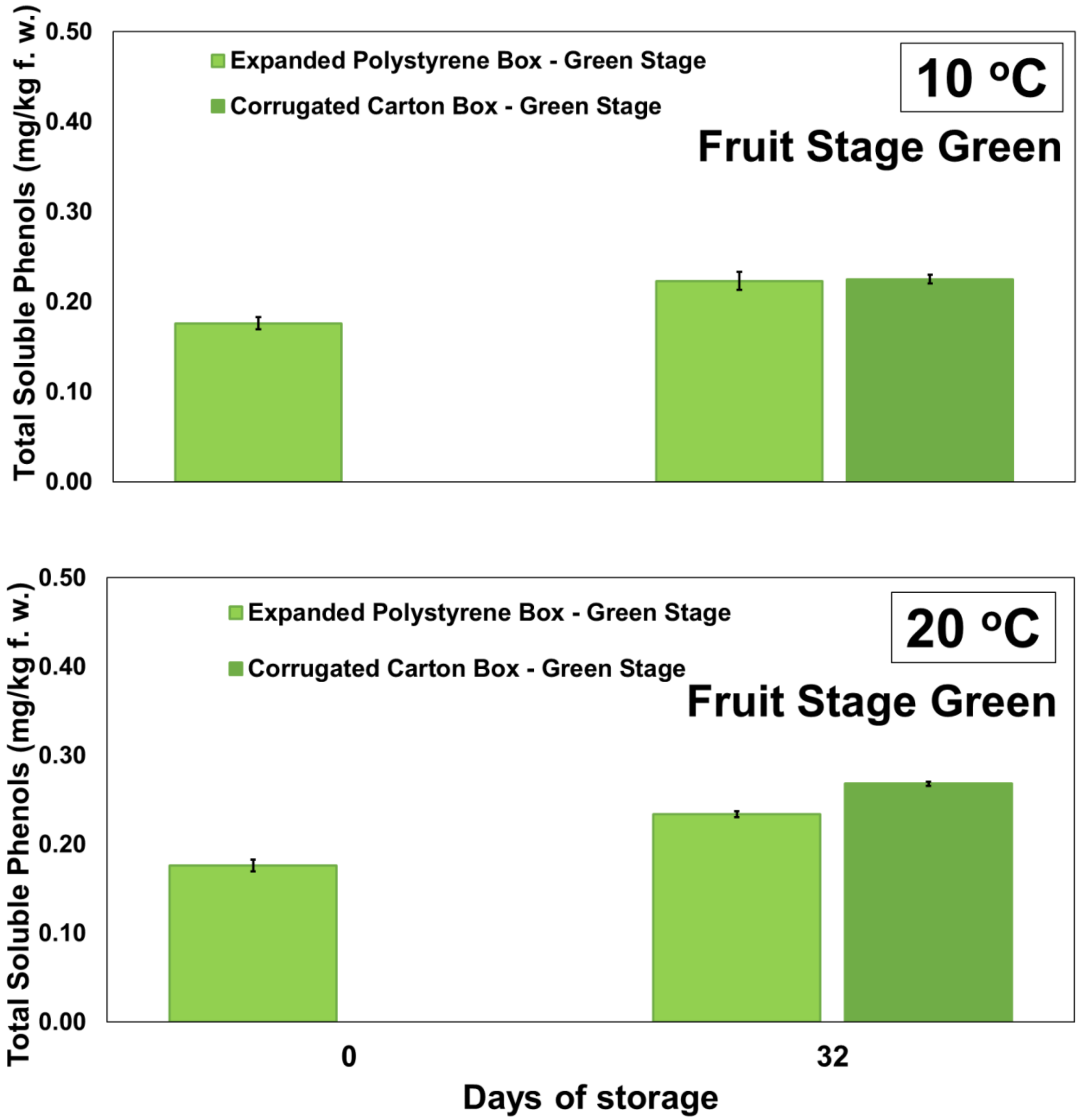


Figure 106. Total soluble phenols content (mg gallic acid equivalents/kg f.w.) of tomato fruits harvested at the green stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

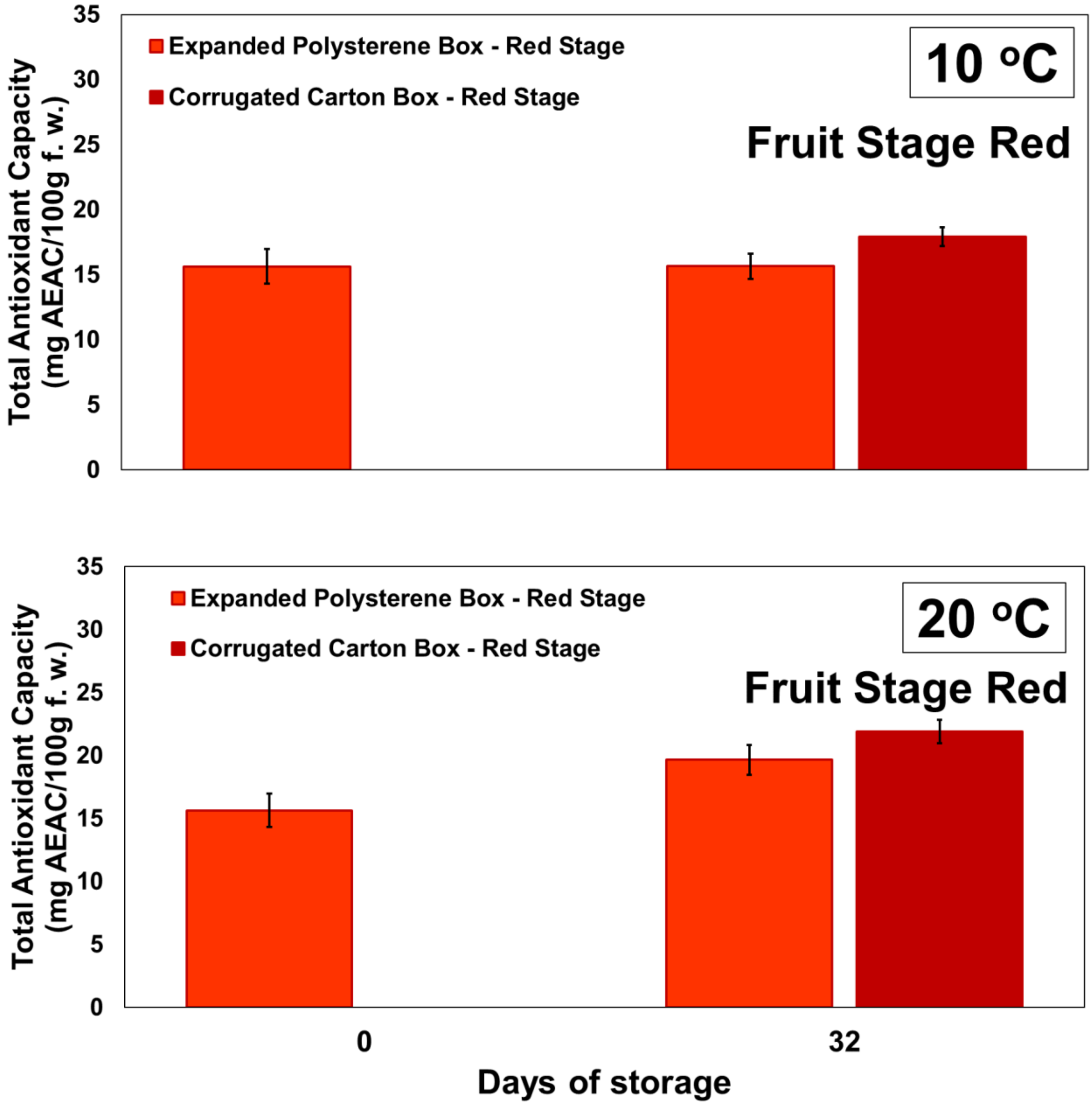


Figure 107. Total antioxidant capacity (mg ascorbic acid equivalents/100g f.w.) of tomato fruits harvested at the red ripe stage and stored inside the EPS and the corrugated carton boxes at 10 and 20°C for 32 days.

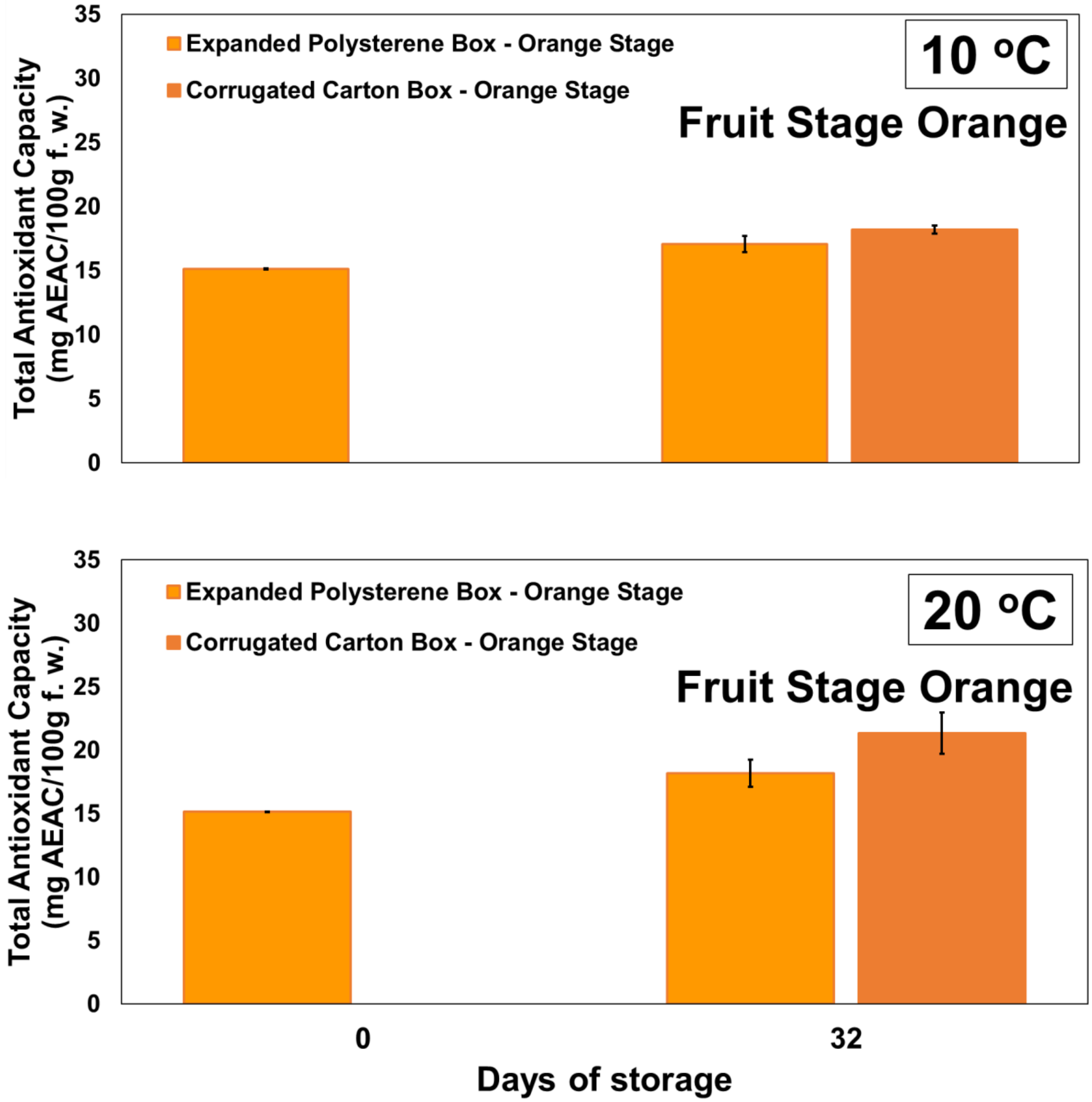


Figure 108. Total antioxidant capacity (mg ascorbic acid equivalents/100g f.w.) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20ºC for 32 days.

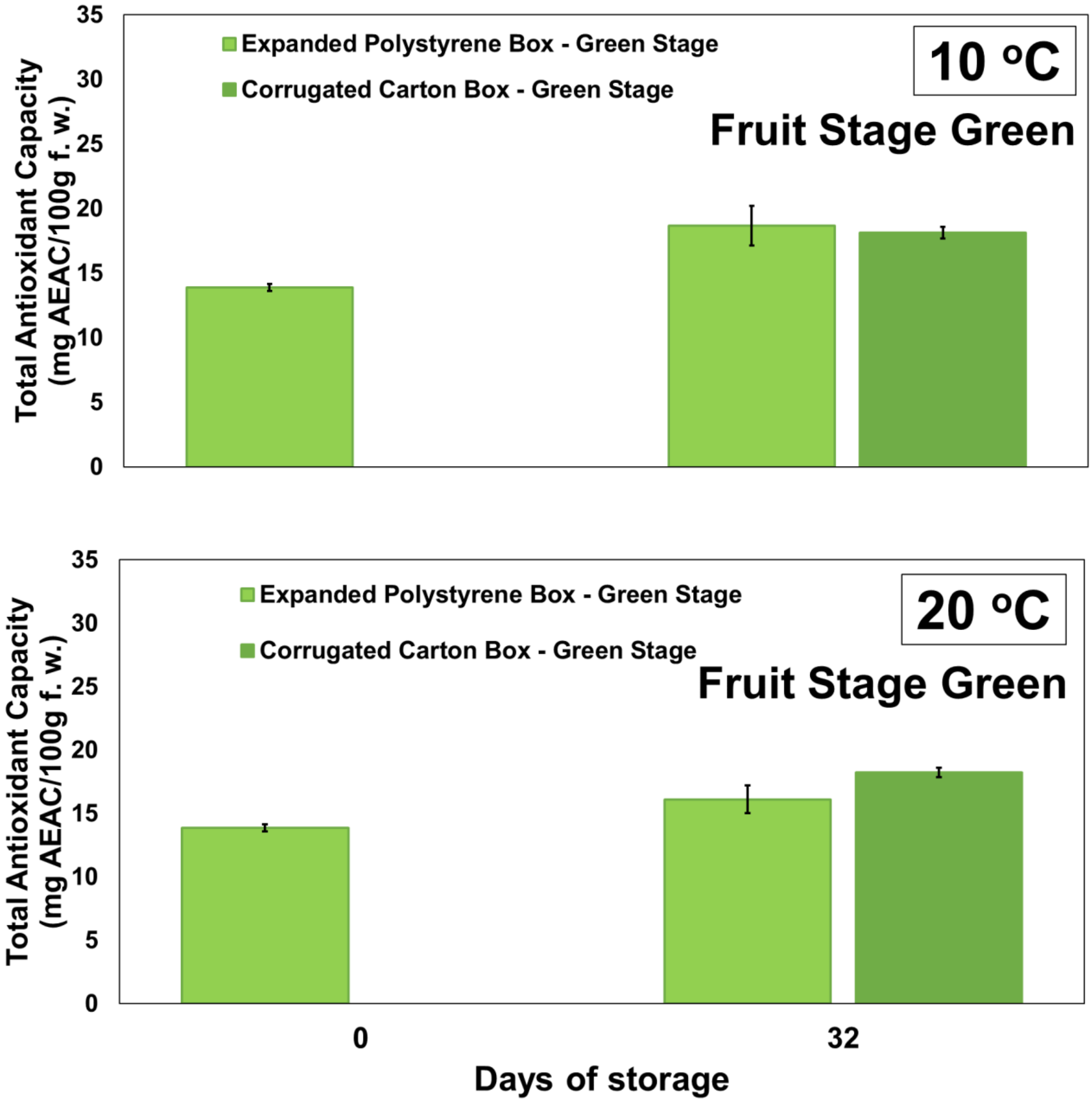


Figure 109. Total antioxidant capacity (mg ascorbic acid equivalents/100g f.w.) of tomato fruits harvested at the orange stage and stored inside the EPS and the corrugated carton boxes at 10 and 20^{o}C for 32 days.

Report on Spinach Storage in EPS package

Abstract

Thirty-nine kilos of freshly harvested baby spinach leaves packed in open plastic bags were transferred to the Laboratory of Vegetable Crops at the Farm of Aristotle University of Thessaloniki. The color and the weight of the spinach leaves was measured with a chroma meter, and they were placed into different packages, in expanded polystyrene (EPS) or in corrugated carton fruit packing boxes. Each type of package was replicated nine times. Data loggers were also placed inside the different packages to record the temperature and the relative humidity conditions inside each package. Afterwards, half packages were placed in 5^{o}C, which is recommended for the storage of leafy vegetables, and the rest in 10^{o}C, which is often encountered during the retail market. The spinach leaves from three packages of each package type and temperature were sampled every five days for weight and color measurements, as well as nutritional components determination, namely dry matter, soluble solids, pH, total antioxidant capacity, soluble phenols and pigments. At both storage temperatures, no significant differences in the temperature levels between the EPS packages and the corrugated carton boxes were observed, while the relative humidity was maintained high in the EPS packages at both temperatures, due to the insulation that is offered by such a closed package system, in contrast to the open corrugated carton packages where a severe variation in the relative humidity was daily recorded, especially in the 10^{o}C. The storage of spinach leaves at 10^{o}C for 15 days resulted in bacterial growth and yellowing appearance in both packaging systems, rendering the spinach leaves unmarketable. Therefore, it is not recommended to store spinach leaves at 10^{o}C for more than 10 days. Similar to the previous studies, between the EPS and the carton boxes, significant differences were only observed in weight loss in both storage temperatures. Neither subjective color evaluation, neither color parameters or other nutritional components were affected by storage in expanded polystyrene packages or open corrugated carton boxes.

Materials and methods

On March 2019, 39 kg of fresh baby spinach leaves were transferred to the Laboratory of Vegetable Crops at the Farm of Aristotle University of Thessaloniki by the commercial company “VEZYROGLOU FARMS” in a refrigerated truck. The leaves were placed inside a plastic bags. Each bag was weighed and color was both subjectively evaluated and measured on 30 randomly selected leaves, before 3 bags (1 replication of 1 kg spinach leaves each) were frozen immediately for analysis, representing Day 0 samples. The remaining bags were placed into EPS or corrugated carton packing boxes. Each type of package was replicated three times. All packages were placed in two different storage temperatures, 5^{o}C and 10^{o}C for 15 days.

Every 5 days samples were taken (3 replications per storage temperature and packaging system) and the weight and color were measured as described above, before further nutritional analysis was performed.

The main nutritional components on each floret were determined, namely dry matter, soluble solids, pH, total antioxidant capacity, soluble phenols and pigments. All the data was statistically processed, and the results are presented below.

Results

Temperature and relative humidity

Temperature was maintained steady without significant variations in both temperatures (Figs. 110 & 111), whereas relative humidity was lower and significantly fluctuated in spinach leaves stored at 10^{o}C in open carton boxes (Figs. 112 & 113).

Weight loss

The weight loss of the spinach leaves is caused due to water loss, which occurs during the respiration and transpiration of living plant tissue, such as the spinach leaves. Both respiration and transpiration rates depend strongly on the relative humidity of the surrounding area of the leaves. High relative humidity decreases the respiration rate.

Spinach leaves stored in EPS packages at 5^{o}C lost 0.09, 0.24 and 0.34% of their initial weight after 5, 10 and 15 days of storage, respectively (Fig. 114), while when stored in corrugated carton boxes at 5^{o}C they lost 0.93, 1.11 and 1.60% of their initial weight after 5, 10 and 15 days, respectively (Fig. 114). When stored at higher temperatures (10^{o}C), the weight loss was higher for both EPS and corrugated carton boxes. In EPS boxes the loss was 0.25, 0.40 and 0.77% of their initial weight, while in corrugated carton boxes the loss was 0.77, 1.64 and 2.04% of their initial weight after 5, 10 and 15 days of storage, respectively (Fig. 114).

According to the above, the weight loss of spinach leaves stored in a conventional commercial packaging system is 3-10 times higher than when stored in EPS boxes even after only five days of storage. The minimal weight loss observed in the EPS package is the result of the protected, insulated packaging system which preserves a high relative humidity and reduces the transpiration rate and consequently the weight loss.

Color

The color of the spinach leaves was measured on thirty leaves of each sample, with a Minolta CR-200 chroma meter. Three different parameters were determined, lightness (L*), chroma (C*) and hue angle (h^o).

Lightness (L*) describes the brightness of a tissue and takes values between 0 that corresponds to black color and 100 that corresponds to white. No significant changes in L* were observed in the spinach leaves stored at 5 ^oC, but there were significant changes in the spinach leaves stored at 10 ^oC for 15 days (Fig. 116). L* increased significantly in both packages used, compared to day 0. Increase in lightness values indicates that the color of the leaves had started to become less bright than at the beginning of the storage, namely less shiny.

Chroma (C*) represents the vividness (high values) or dullness (low values) of a color. No significant changes in C* were observed in the spinach leaves stored at 5 ^oC, but there were significant changes in the spinach leaves stored at 10 ^oC for 15 days (Fig. 117). L* increased significantly in both packages used, compared to day 0.

Hue angle describes the hue of the color and each degree corresponds to a specific color (0^o for red, 90^o for yellow, 180^o for green, 270^o for blue). No significant changes in H^o were observed in the spinach leaves stored at either 5 or 10 ^oC (Fig. 118).

According to the color changes, it is concluded that the only changes were observed in the spinach leaves stored at 10^oC in both packages within 15 days of storage

Nutritional quality

Dry matter increases in vegetables when there is water loss due to transpiration; thus, rendering the tissue less tender during consumption. During the first 10 days of storage at both 5 and 10^oC, dry matter in spinach leaves stored in both packages remained constant (9%), while after 15 days of storage, it increased significantly to 10% in both packages when stored at 5^oC

and only in corrugated carton box when stored at 10^{o}C (Fig. 119). This difference was observed because the EPS box retained high relative humidity in the inside atmosphere.

Total soluble solids content includes all sugars and organic acids that are responsible for the flavor in vegetables. No significant changes were observed in total soluble solids content at both storage temperatures and packages during the 15 days storage (Fig. 120).

During the first 10 days of storage, pH remained at the initial levels in spinach leaves stored at 5 or 10^{o}C in EPS and in corrugated carton boxes (Fig. 121). An increase was observed in spinach leaves stored at 10^{o}C for 15 days of storage in both EPS and corrugated carton boxes (Fig. 121). However, the pH increase is 0.2 units or less (6.5-6.7), which cannot be considered a significant nutritional change, and neither can be perceived during consumption.

In spinach leaves stored at 5^{o}C, chlorophylls decreased after 10 days of storage in EPS boxes, and after 15 days of storage in EPS or corrugated carton boxes (data not shown). In spinach leaves stored at 10^{o}C, chlorophylls decreased after 15 days of storage in both EPS and corrugated carton boxes. The decrease in chlorophylls, which are responsible for the green colour of leaves, explains the yellowing that was observed during storage.

Total carotenoids remained at the initial levels and only decreased slightly in spinach leaves stored at 10^{o}C for 15 days in both EPS and corrugated carton boxes (Fig. 122).

Phenols are one group of the main antioxidants in vegetables and, along with other components, they comprise the total antioxidant capacity. A change in phenols' content was observed only after 15 days of storage in spinach leaves stored at 5^{o}C in corrugated carton box and at 10^{o}C in EPS and corrugated carton box (Fig. 123).

Total antioxidant capacity decreased in spinach leaves stored at 5^{o}C in corrugated carton box for 10 days and in EPS for 15 days and in spinach leaves stored at 10^{o}C in both EPS and corrugated carton box for 10 and 15 days, while it increased significantly in spinach leaves stored at 5^{o}C in corrugated carton boxes for 15 days (Fig. 124).

Conclusions

According to the above results, it is concluded that the quality of baby spinach leaves, in terms of green colour preservation and minimal weight loss, may be maintained at acceptable levels for 15 days when stored at 5^{o}C in EPS boxes or for 10 days when stored at 10^{o}C in EPS boxes. When the spinach leaves were stored for 15 days at 10^{o}C in either the EPS or the corrugated carton boxes, bacterial growth was observed, rendering the spinach leaves unmarketable.

No significant differences in the nutritional composition of spinach leaves between the two packaging systems were found.

Photo 20. Baby spinach leaves upon their arrival from Vezyroglou Farms to the Postharvest facilities of the Lab of Vegetable Crop AUTH.

Photo 21. Baby spinach leaves packaged in perforated plastic bag and placed in EPS or corrugated carton box or during storage at 5 or 10°C for 15 days.

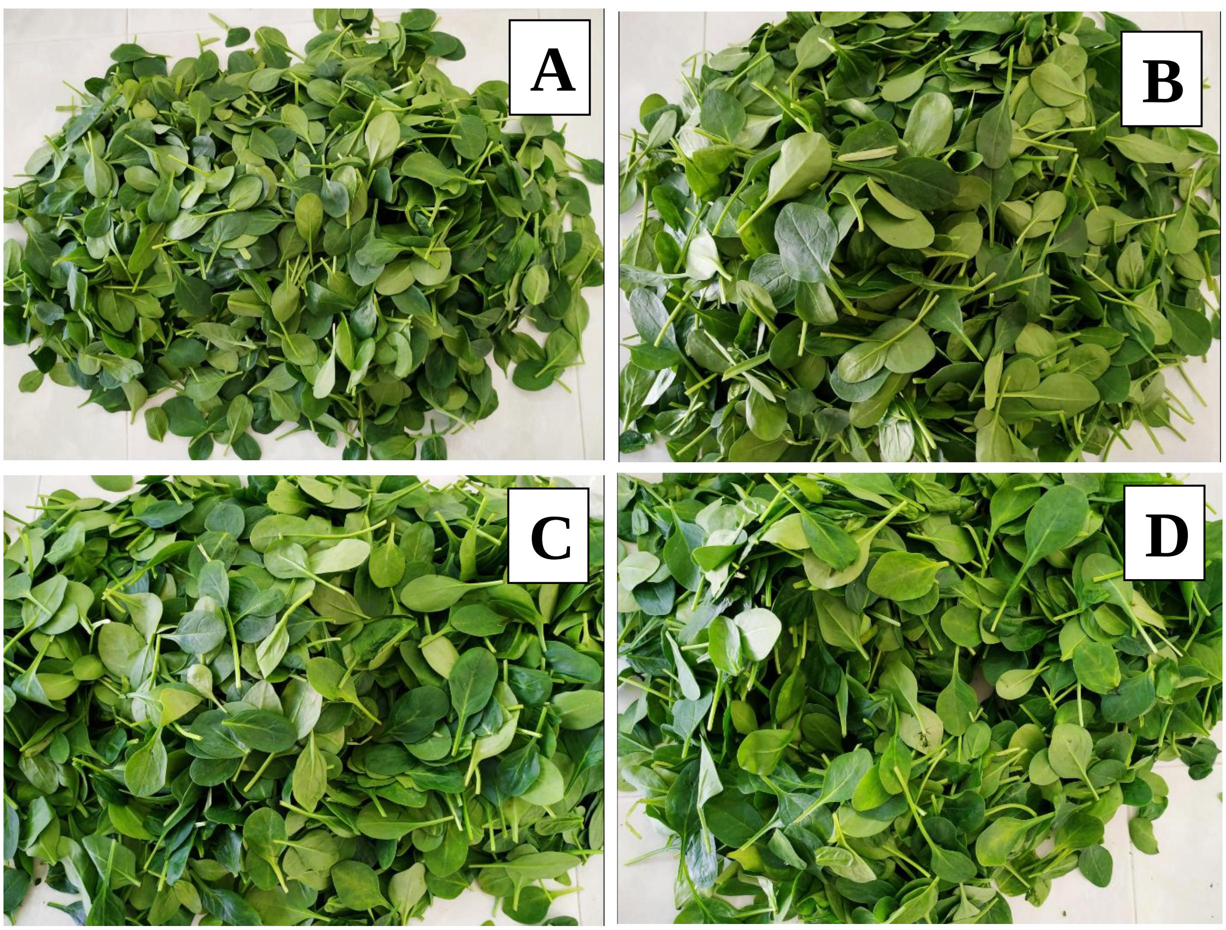


Photo 22. Baby spinach leaves after 15 days of storage at 5oC (A, B) or 10oC (C, D) packaged in perforated plastic bag and placed in EPS (A, C) or corrugated carton boxes (B, D).

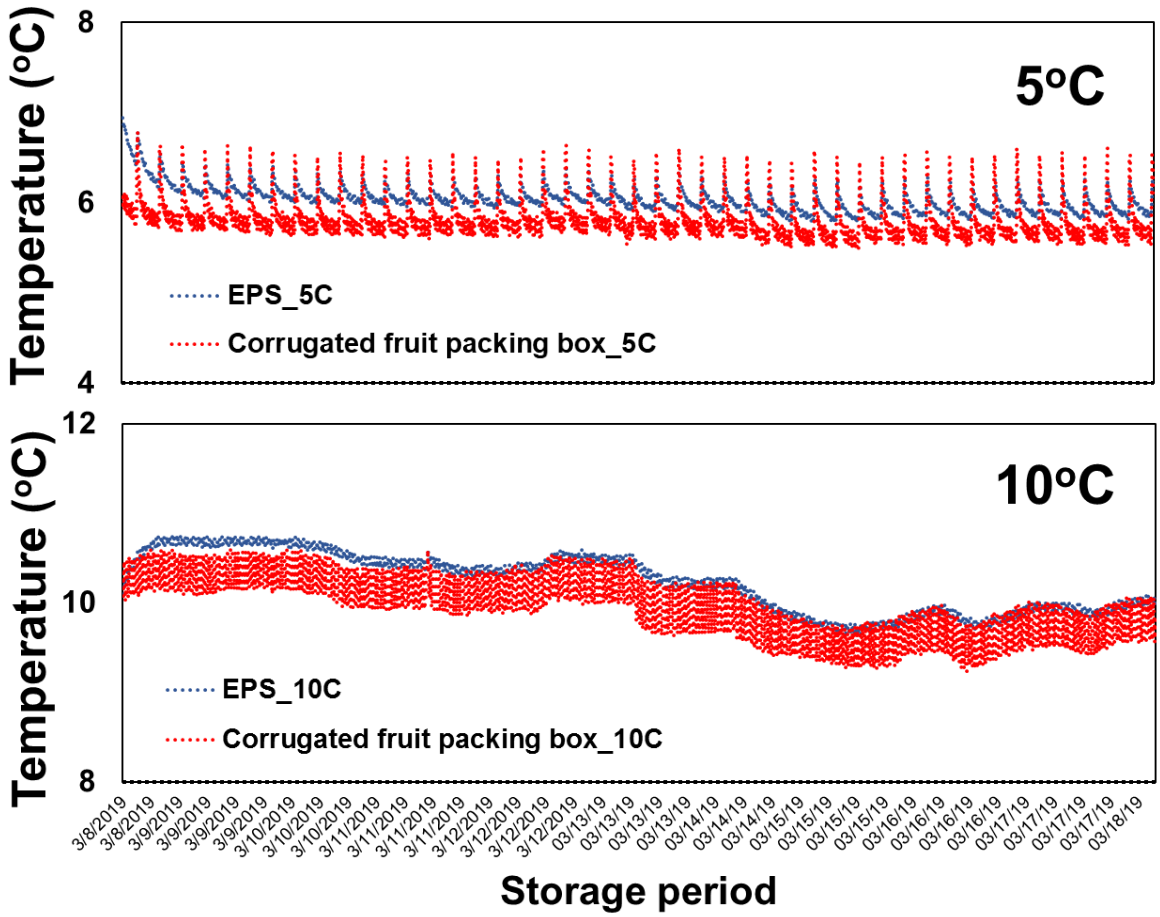


Figure 110. Temperature inside the EPS and the corrugated carton boxes of spinach leaves during storage at 5 and 10°C.

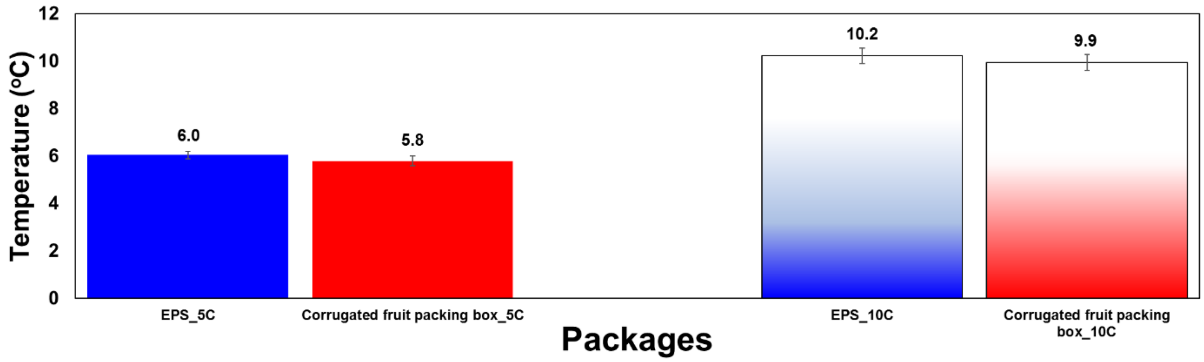


Figure 111. Mean temperature (± S.E.) inside the EPS and the corrugated carton boxes of spinach leaves during storage at 5 and 10oC.

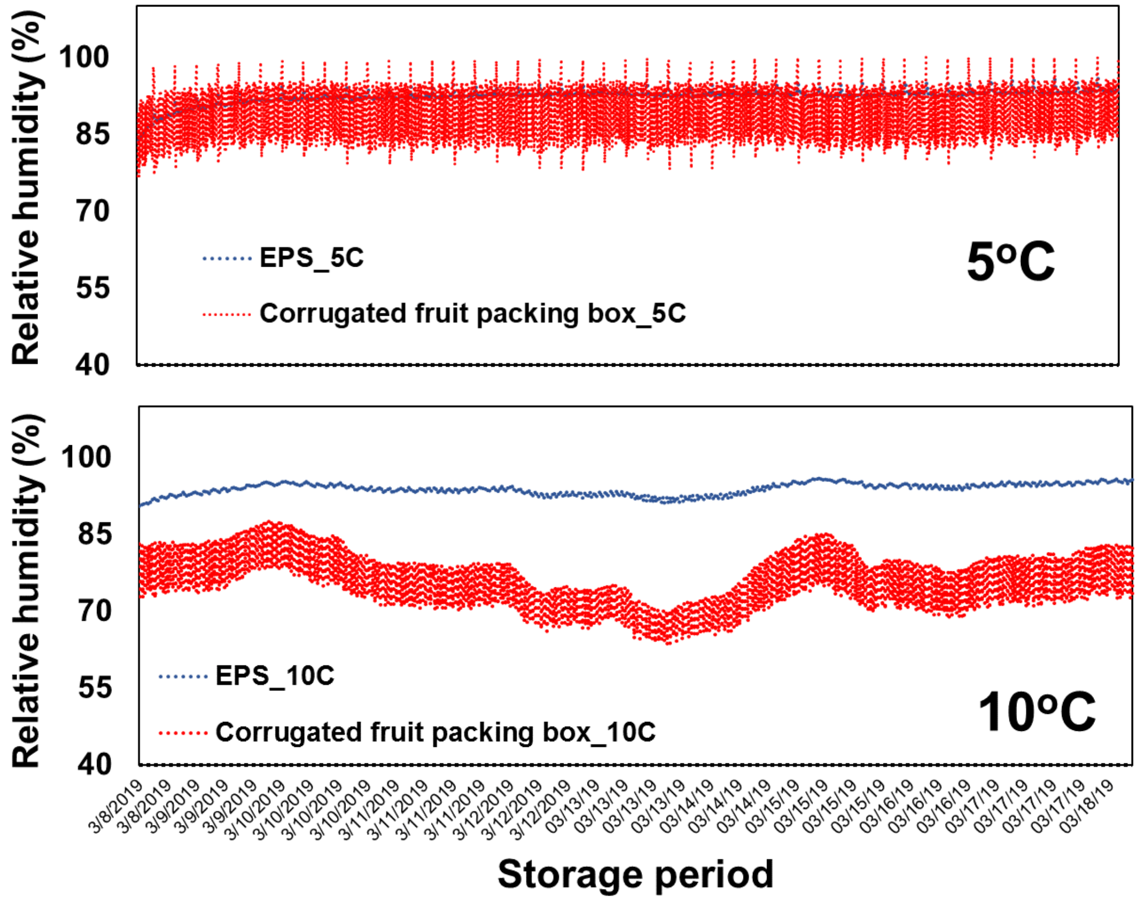


Figure 112. Relative humidity inside the EPS and the corrugated carton boxes of spinach leaves during storage at 5 and 10°C.

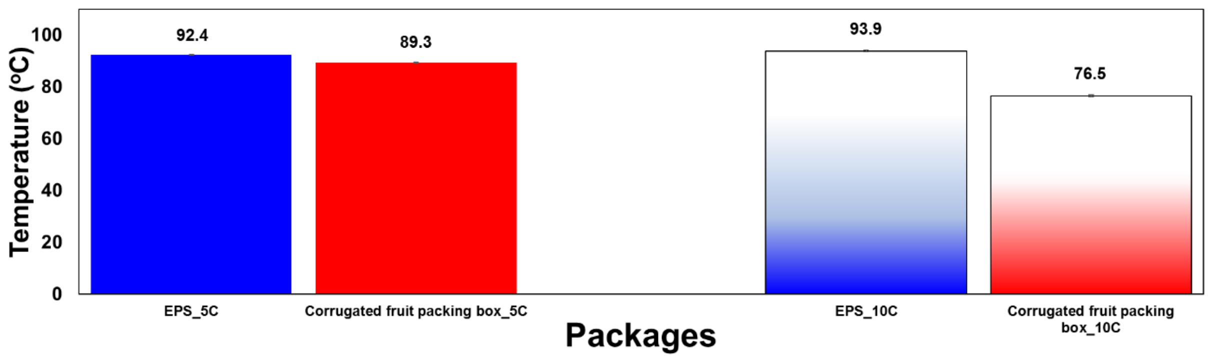


Figure 113. Mean relative humidity (± S.E.) inside the EPS and the corrugated carton boxes of spinach leaves during storage at 5 and 10ºC.

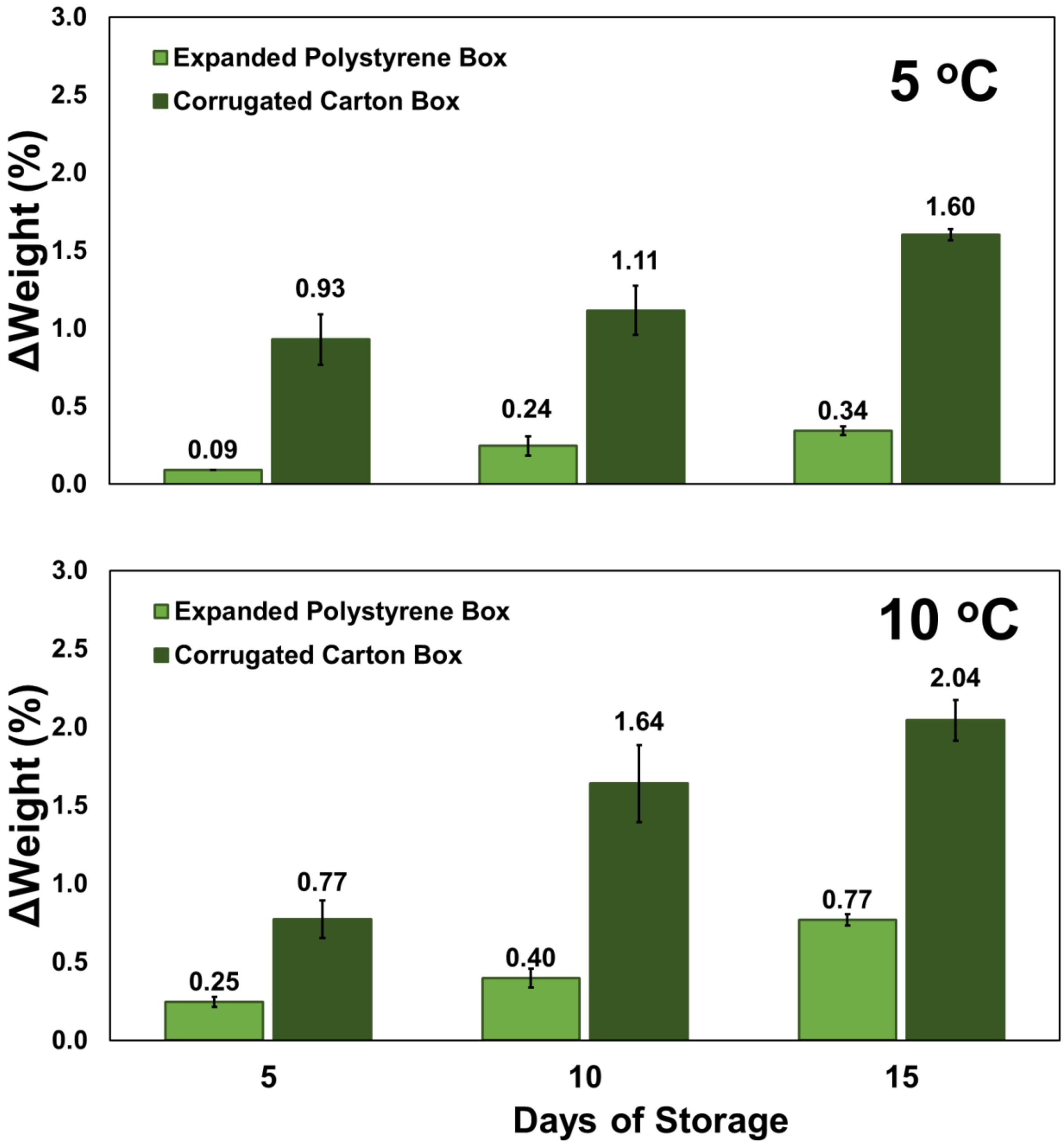


Figure 114. Δweight (%) (± S.E.) of spinach leaves during storage at 5 and 10oC in EPS and corrugated carton boxes.

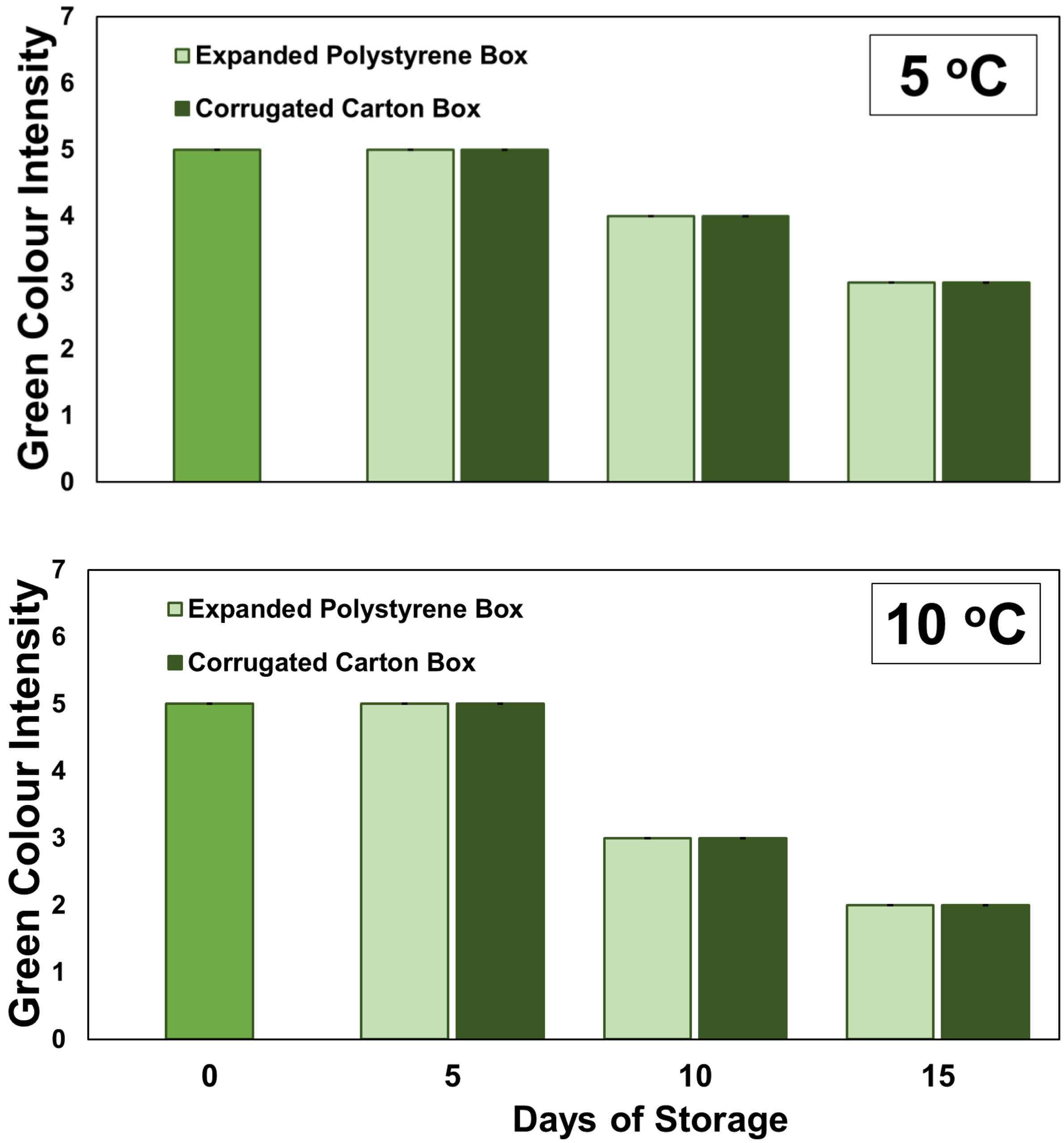


Figure 115. Green color intensity (%) (± S.E.) of spinach leaves during storage at 5 and 10ºC in EPS and corrugated carton boxes.

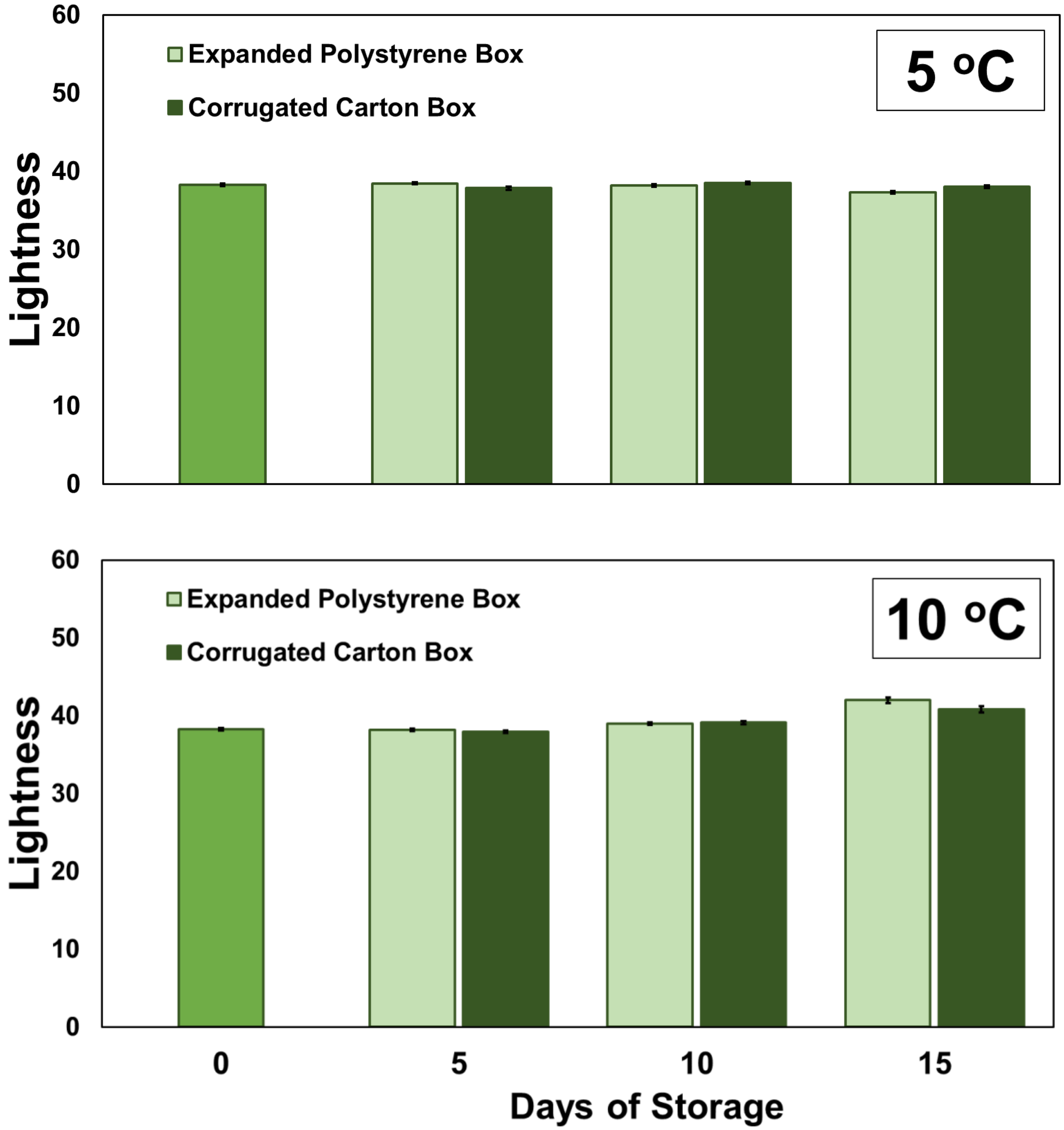


Figure 116. Lightness (± S.E.) of spinach leaves during storage at 5 and 10^{o}C in EPS and corrugated carton boxes.

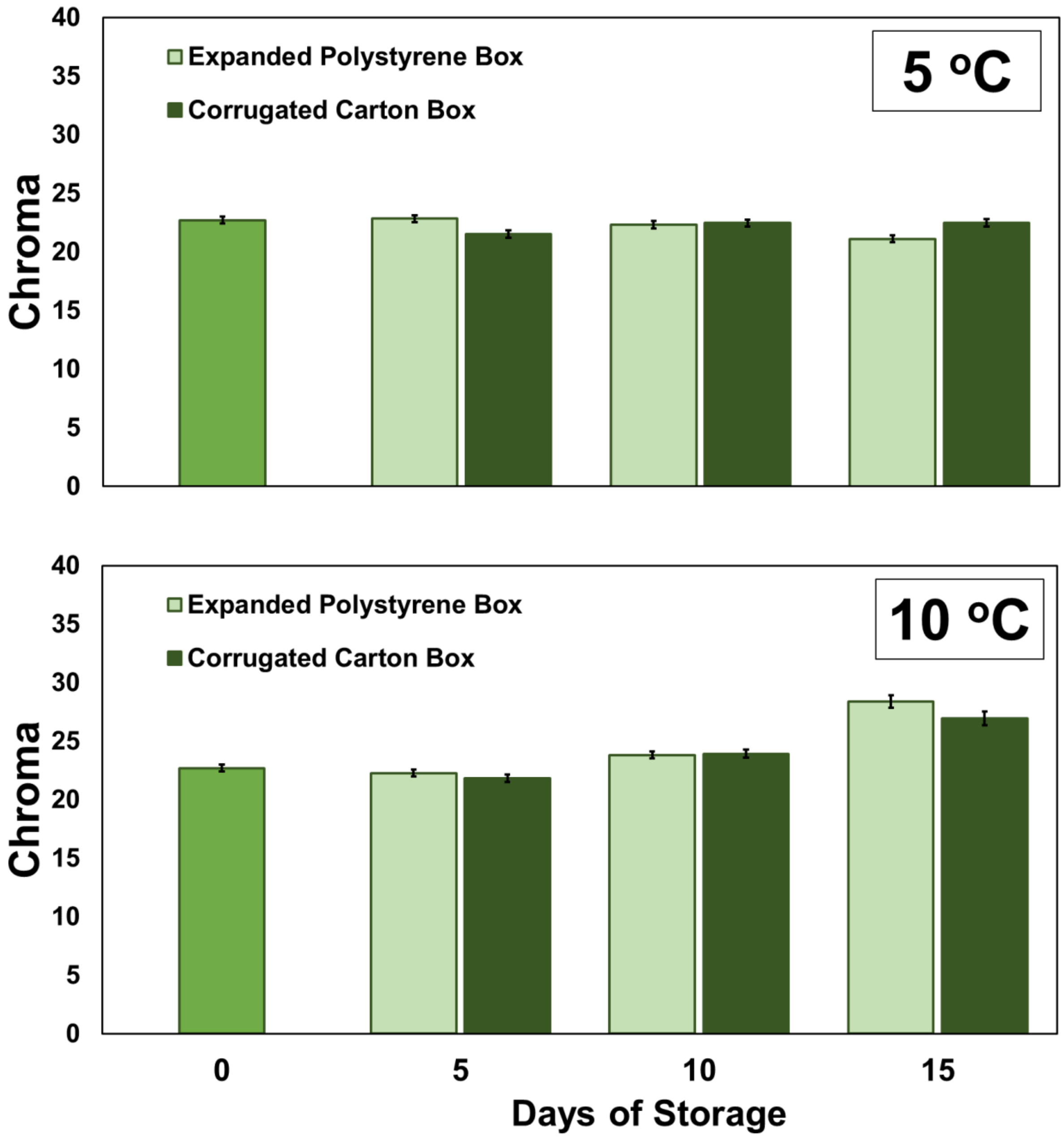


Figure 117. Chroma (± S.E.) of spinach leaves during storage at 5 and 10°C in EPS and corrugated carton boxes.

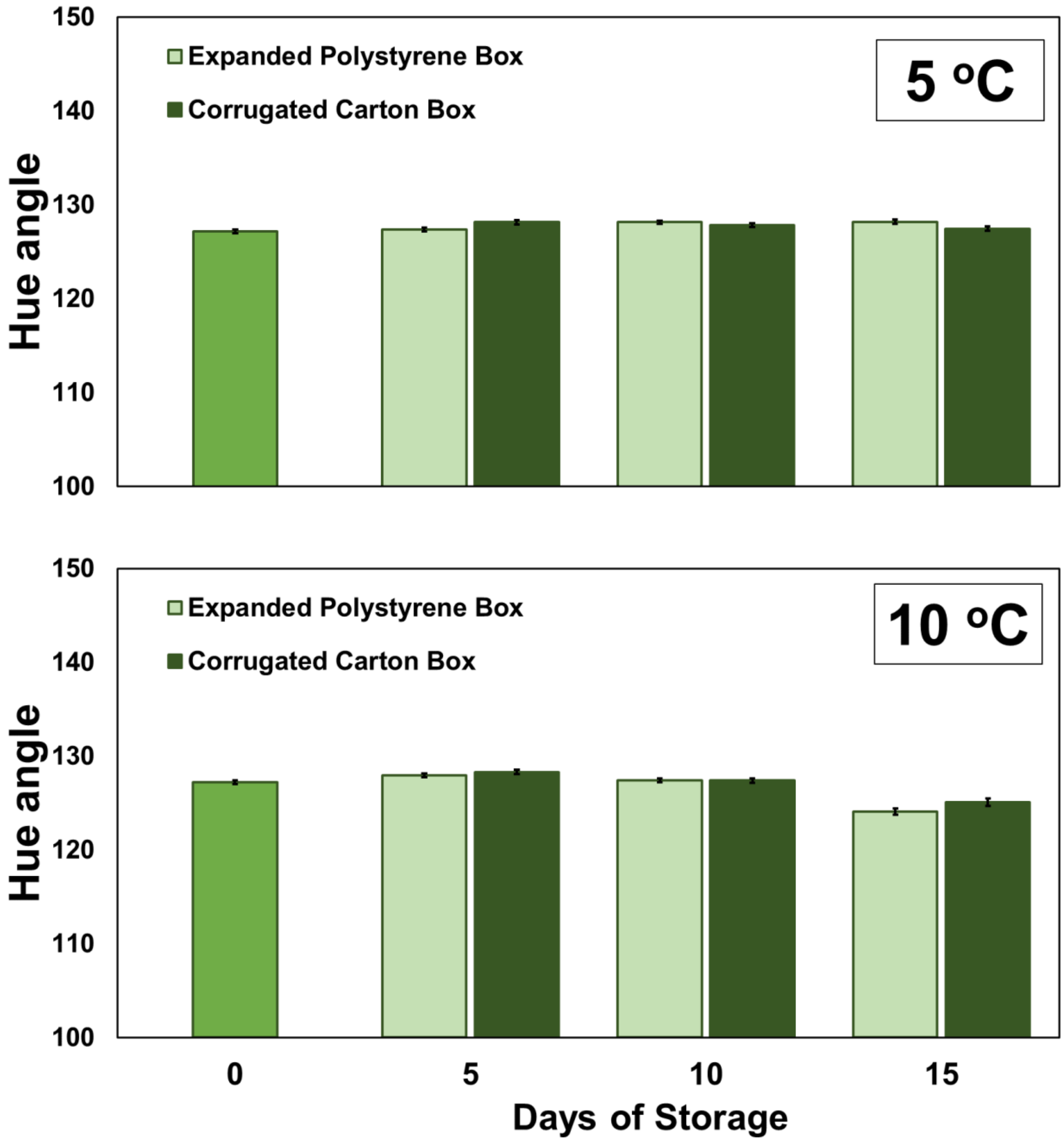


Figure 118. Hue angle (± S.E.) of spinach leaves during storage at 5 and 10ºC in EPS and corrugated carton boxes.

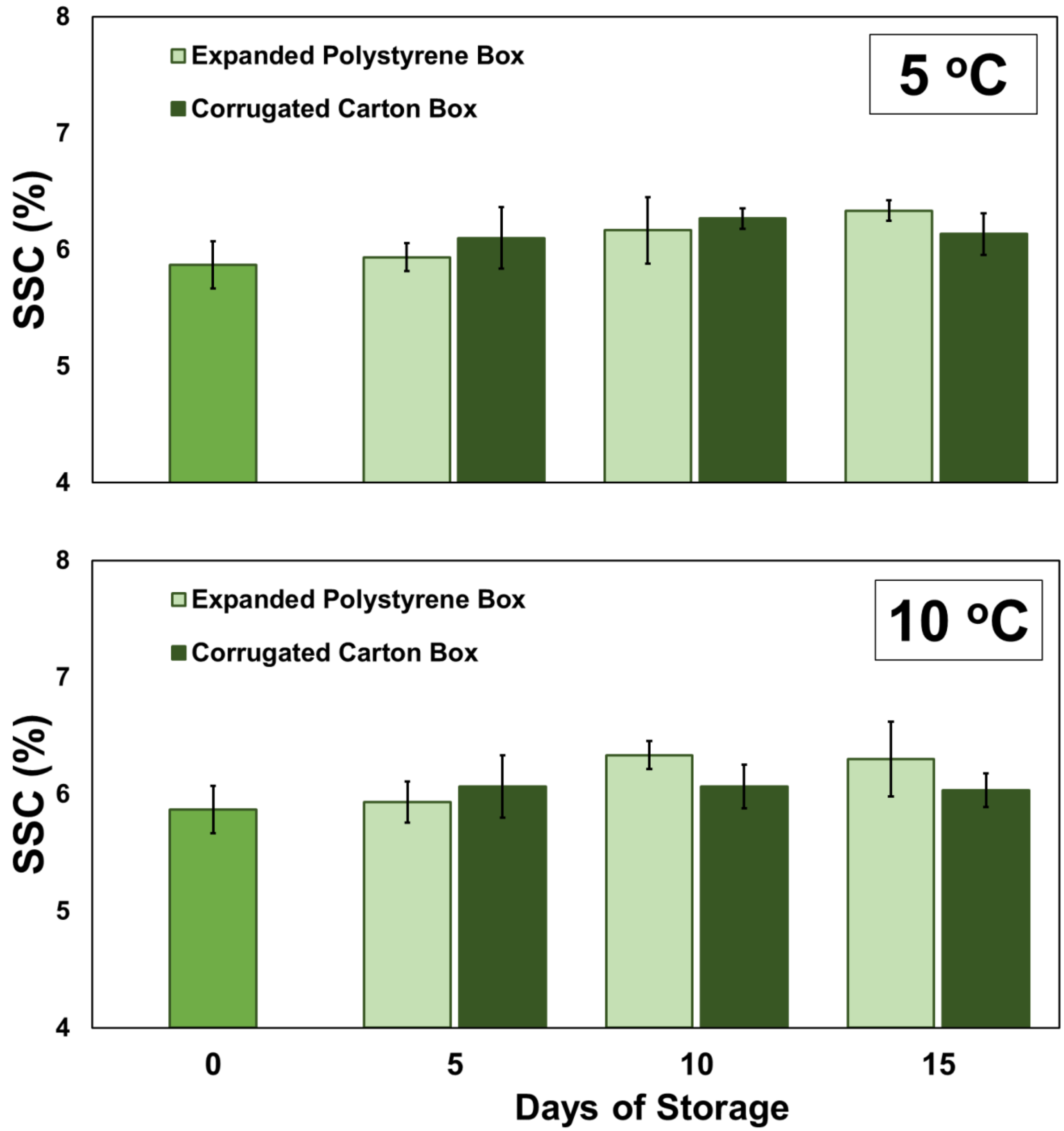


Figure 119. Soluble solids content (SSC) (%) of spinach leaves during storage at 5 and 10ºC in EPS and corrugated carton boxes.

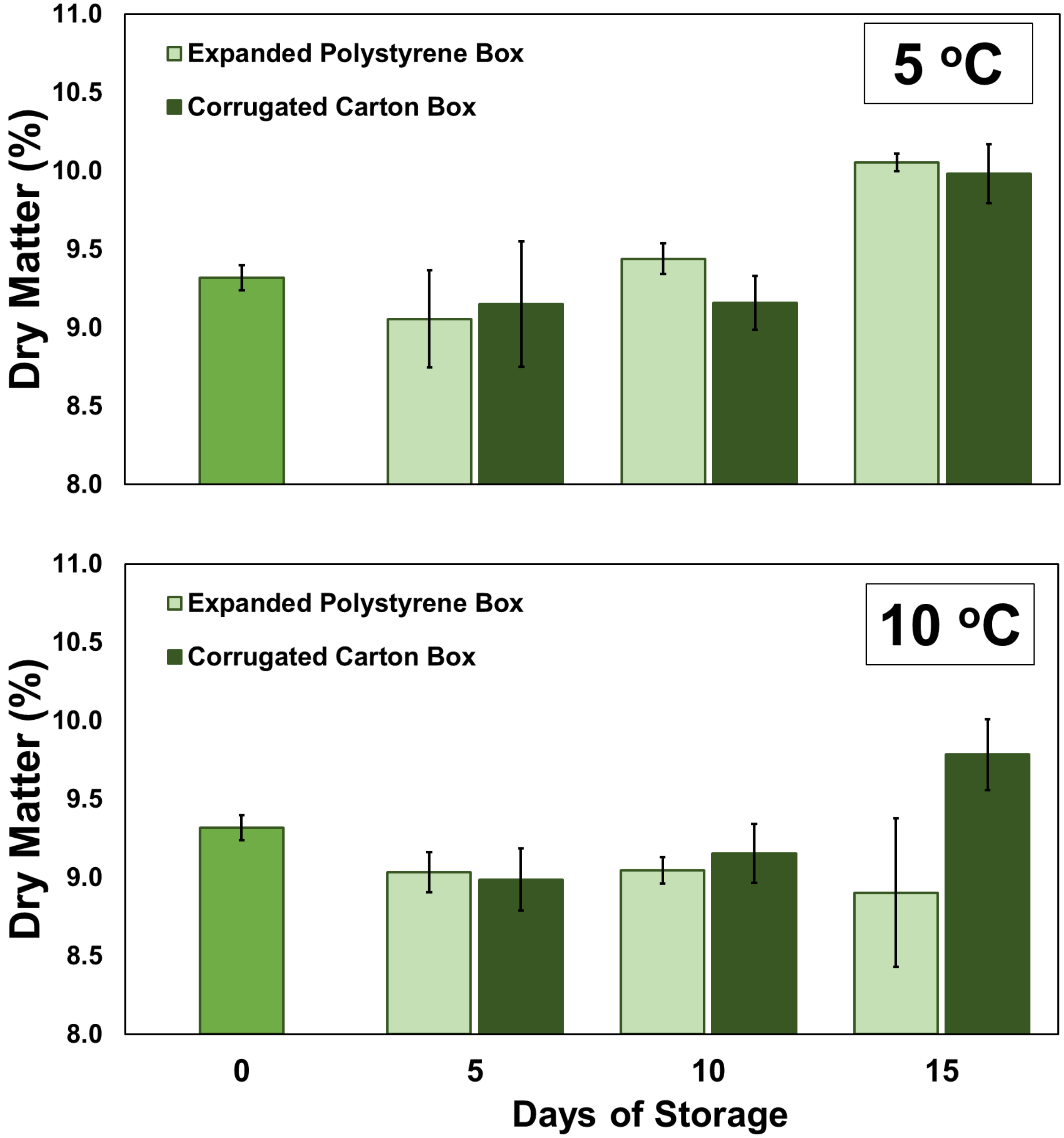


Figure 120. Dry matter content (%) of spinach leaves during storage at 5 and 10°C in EPS and corrugated carton boxes.

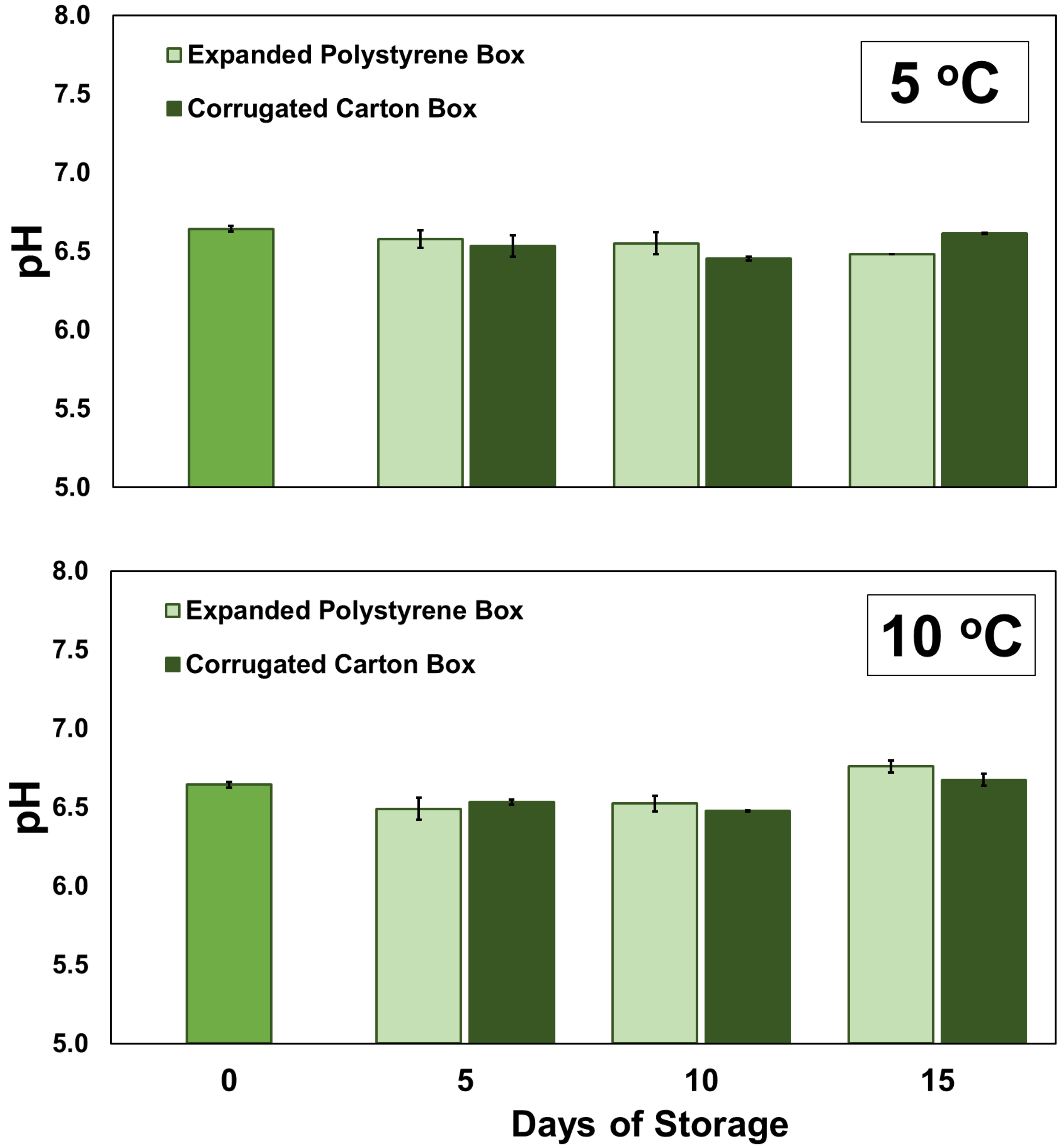


Figure 121. The pH of spinach leaves during storage at 5 and 10^{o}C in EPS and corrugated carton boxes.

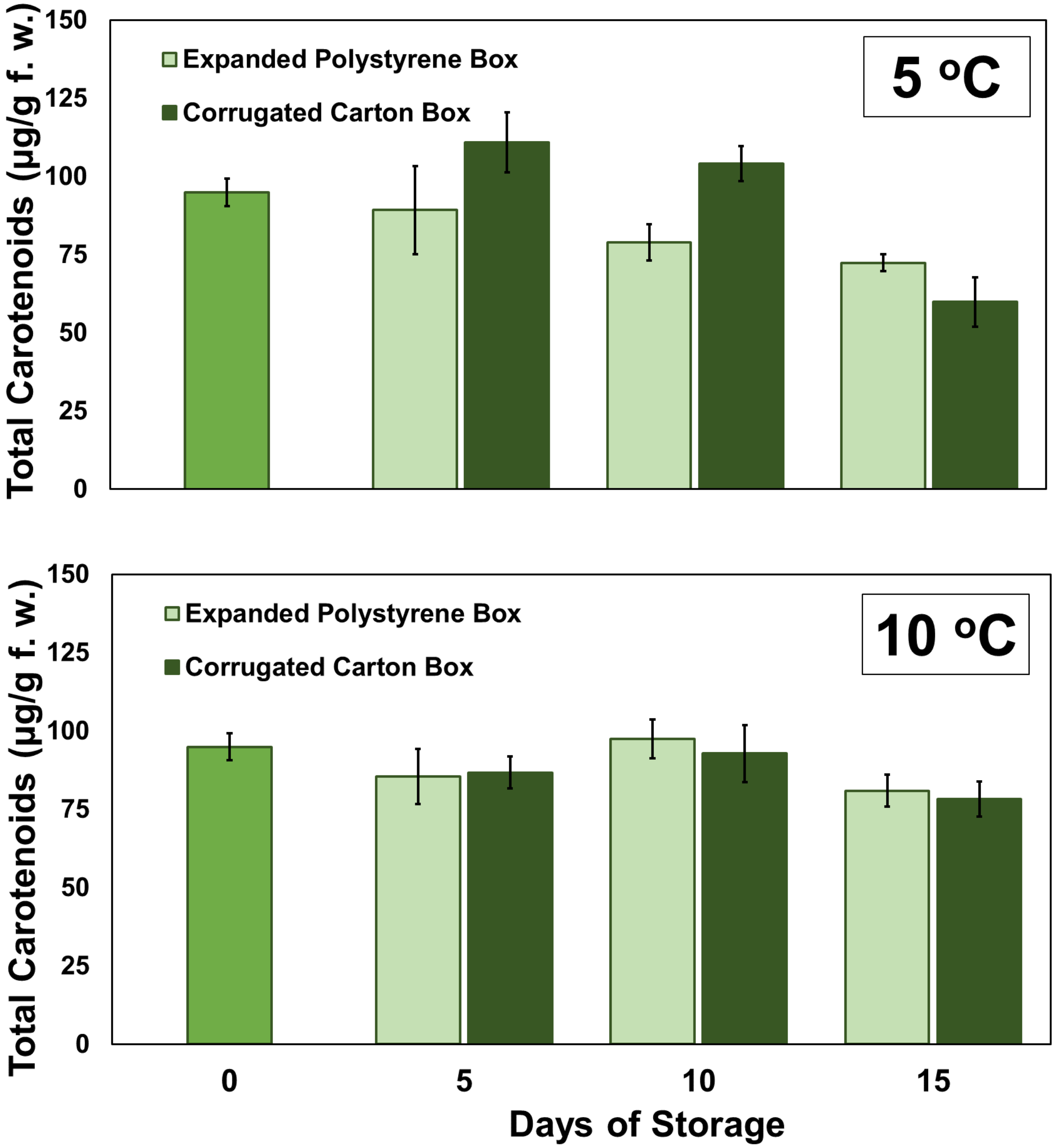


Figure 122. Total carotenoid content (µg/g f.w.) of spinach leaves during storage at 5 and 10°C in EPS and corrugated carton boxes.

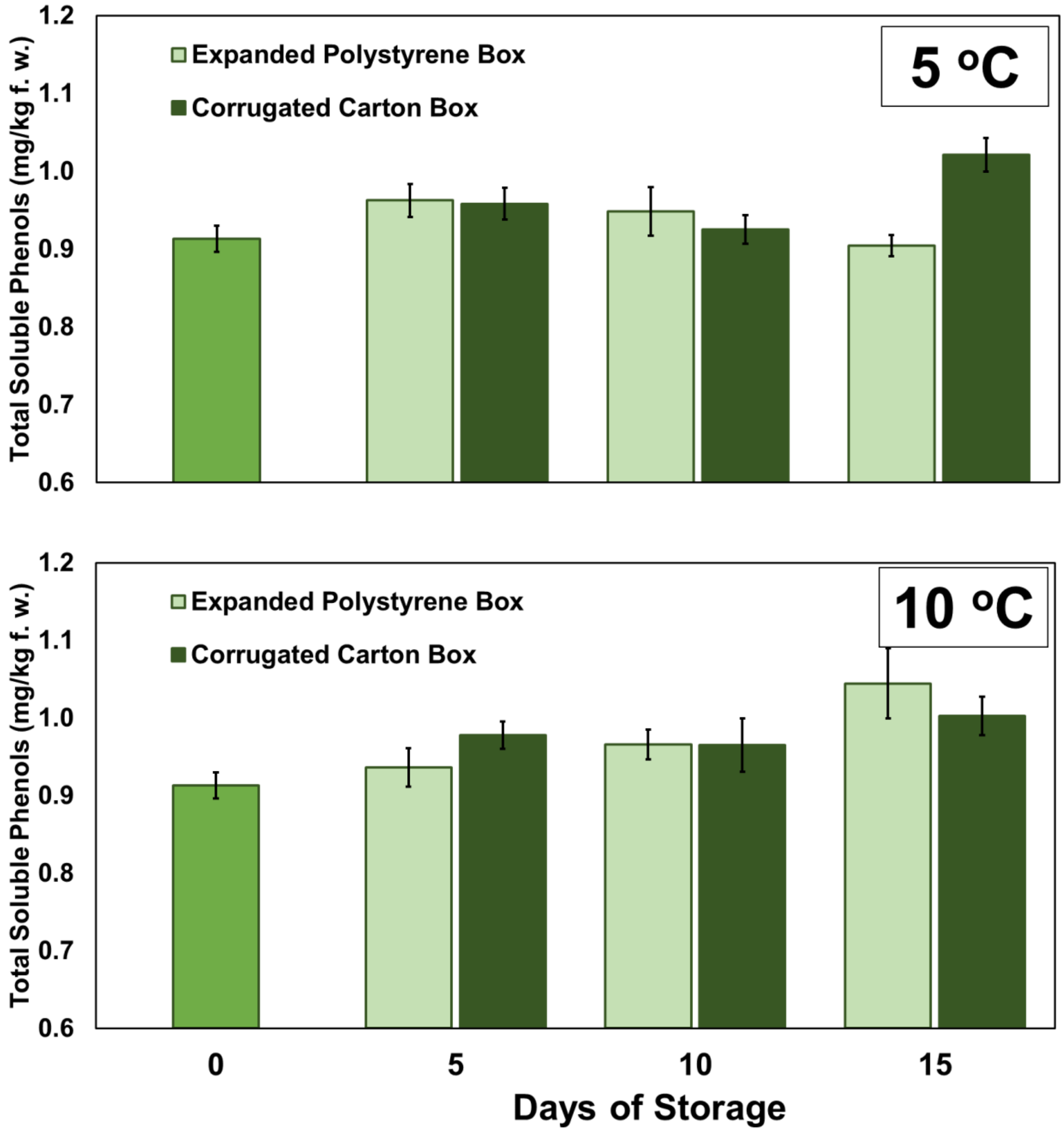


Figure 123. Total soluble phenols content (mg gallic acid equivalents/kg f.w.) of spinach leaves during storage at 5 and 10^{o}C in EPS and corrugated carton boxes.

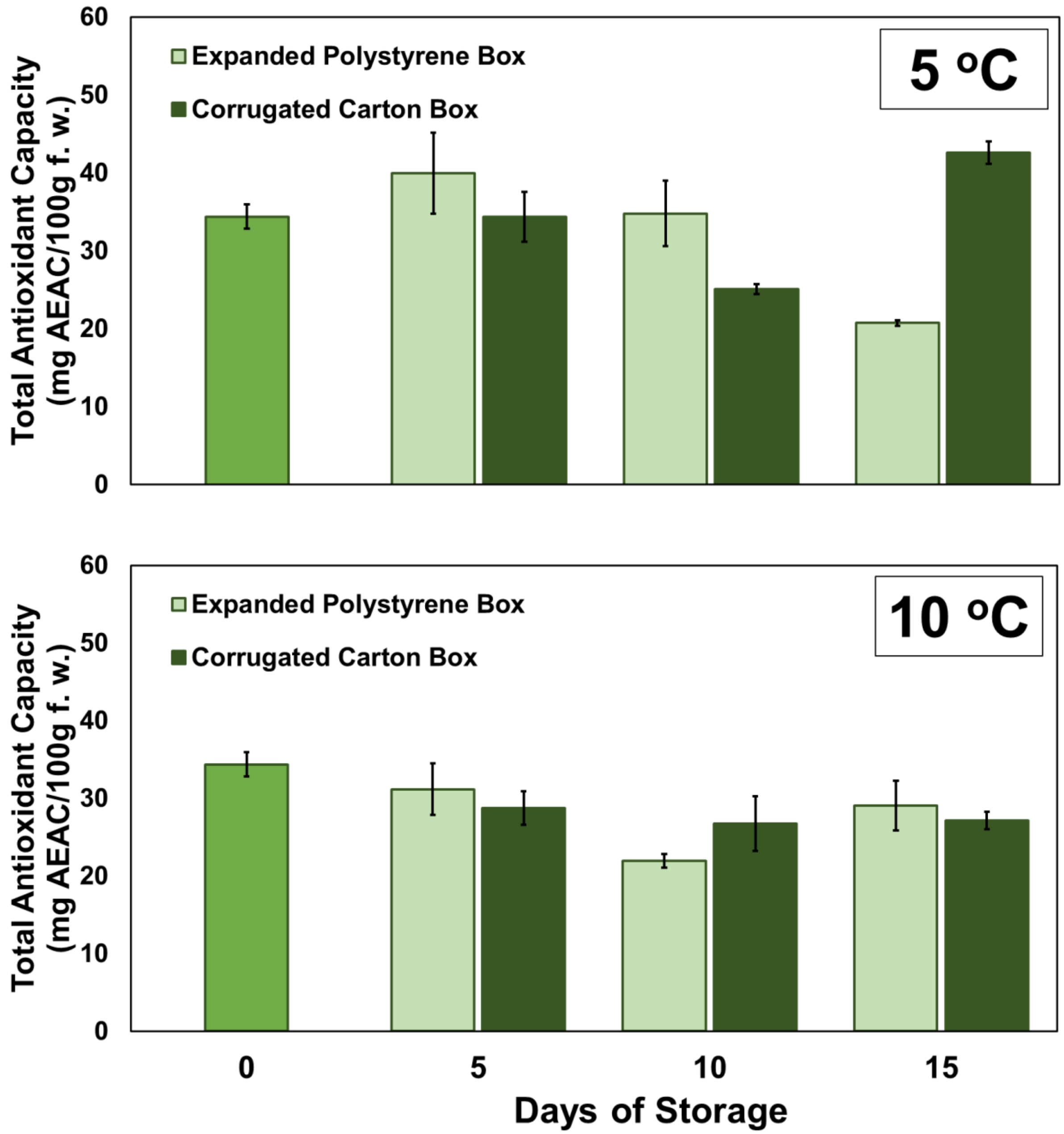


Figure 124. Total antioxidant capacity (mg ascorbic acid equivalents/100g f.w.) of spinach leaves during storage at 5 and 10ºC in EPS and corrugated carton boxes.